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INFLUENCE OF GLYPHOSATE AND CROP COMPETITION ON CONTROL OF QUACK GRASS *(AGROPYRON REPENS* (L.) BEAUV.)

by

© D.R. Valgardson

A THESIS

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled

Influence of Glyphosate and Crop Competition on Control of Quack Grass *(Agropyron repens* (L.) Beauv.)

submitted by D.R. Valgardson in partial fulfilment of the requirements for the degree of Master of Science in Weed Science and Crop Ecology.

ABSTRACT

Greenhouse and field experiments were concerned with effects of the new herbicide glyphosate (N-(phosphonomethyl)glycine) on quack grass (*Agropyron repens* (L.) Beauv.), and certain annual crops, together with crop productivity and competition with quack grass after cultivation or spraying and cultivation.

Greenhouse experiments with shoot-bearing quack grass rhizomes indicated that rhizomes having several shoots,compared with rhizomes severed between the shoots, were approximately equally susceptible to injury from glyphosate foliage-spray. Activity of glyphosate on unsprayed shoots along an intact rhizome after sprays applied to an isolated shoot at another position on the same rhizome, indicated movement of the toxic chemical in both directions along the rhizome. In some cases an unsprayed shoot along this rhizome was by-passed leaving it only partially affected while killing one farther away from the sprayed shoot. Similarly, apparently healthy segments remained between dead portions in some of the excavated rhizomes of quack grass sprayed in the field.

Barley,rye and oats sown into flats of soil sprayed with 2.24, 4.48, 6.72 and 8.96 kg/ha a.e. glyphosate were not affected by the herbicide but rapeseed in the seedling stage and again at flowering time was injured to some extent by the three higher dosages and buckwheat was affected by the highest rate. In the field there was no evident injury to these crops seeded after spraying quack grass with an adequate dosage of 2.80 kg/ha glyphosate.

Quack grass sprayed at the heading stage, in the field, and not

cultivated afterwards was very susceptible to the herbicide. Periodic removal of top growth indicated that maximum limitation of new shoots from rhizomes occurred within two days after spraying 1.68 kg/ha or 2.80 kg/ha glyphosate.

Cultivation before and sixteen days after spraying glyphosate at the 3-4 leaf stage was as effective as the treatment at heading stage that had no cultivation afterwards.

Seeded quack grass, during its seedling year, competed vigorously with oats, buckwheat, spring sown winter rye and rapeseed; arranged in order of their decreasing effect on the quack grass.

Plots with densely established older quack grass receiving foliage sprays of 2.80 kg/ha glyphosate in the early spring, then cultivated and seeded, ten days later, after grass top growth had died, had, at harvest time, reductions up to 98% quack grass and increases ranging from 30 to 400% in crop yields compared with controls that were only cultivated once or twice prior to seeding. Crops arranged in order of their decreasing effects on quack grass were oats, buckwheat, rapeseed and winter rye. Crops in order of decreasing effects of quack grass on crop yield were oats, rapeseed, buckwheat, and rye.

Fall seeded rye and spring seeded oats were equally productive and about equally effective in controlling growth of quack grass. Superior crop yields came from glyphosate sprayed plots. Seeding winter rye in the fall shortly after harvesting oats from quack grass plots sprayed in the spring of the same year greatly reduced multiplication of surviving grass during the following year. Cultivation twice in the fall was less effective for quack grass control than a single

cultivation in the fall followed by a second cultivation in the next spring. Fall or spring spray treatments with glyphosate before spring cultivation and seeding, were about equally effective, and superior to cultivation only, for quack grass control and increased crop production.

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Table of Contents

Page

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

INTRODUCTION

Although quack grass (*Agropyron repens* (L.) Beauv.) is a hardy perennial grass which has some value for forage production and for soil conservation, its presence as a weed in agricultural land causes serious losses in crop production (Harvey 1973). Since existing methods for control of quack grass have important limitations, to which later reference is made, there has been a continuing need for further relevant research. The present investigation was therefore undertaken to study competition between various annual crops and quack grass in relation to yields of both the weed and the crops. There was concurrent emphasis on evaluation of various dosages of a new experimental translocated herbicide, glyphosate (N-(phosphono-methyl)glycine), for control of quack grass alone and in association with the production of crops under field conditions. Additional greenhouse and growth chamber experiments were also included to study evidence of movement of glyphosate in quack grass rhizomes and potential residual effects of the herbicide on early development of crops seeded in soil sprayed with this compound.

LITERATURE REVIEW

General characteristics of *Agropyron repens* (L.) Beauv.

Agropyron repens (L.) Beauv., commonly known as quack grass, couch grass, or twitch grass, has been described by Palmer and Sagar (1963) as being a highly variable, rhizome producing, perennial grass species. The plant, bluish to yellowish green in color, may have a prostrate or erect growth habit (Palmer and Sagar 1963) and develop to a height of 30.5-122 cm (1-4 feet) (Frankton 1955). The leaf blades, varying from 0.63-1.26 cm (¼-½ inch) in width (Holmgren and Anderson 1971), can range from glabrous to densely hairy and the inflorescence, a spike, may vary from loose to compact (Palmer and Sagar 1963). Spikelets, about 1.26 cm (½ inch) long, are sessile and occur alternately with the broad side against the stem (Frankton 1955). He describes the rhizomes as white or yellowish in color with a diameter of 3.2 mm (1/8 inch) and having pointed tips. According to Palmer and Sagar (1963) 1 to 4 primary rhizomes may develop with as many as 150 secondary rhizomes. Nodes, covered with scale leaves, are positioned along the rhizomes and may develop into buds or new branches.

Quack grass, a native of Europe and present in agricultural areas across Canada (Frankton 1955), does not grow well in acid soils (Palmer and Sagar 1963) but is salt tolerant (Holmgren and Anderson 1971) and prefers arable land in the temperate regions of the world (Palmer and Sagar 1963). The plant is self-sterile (Palmer 1958) and, according to Palmer and Sagar (1963), reproduces mainly vegetatively, by rhizomes, forming genetically pure stands. Palmer (1958) and

Sagar (1960) tested spikes from several quack grass stands and found that nearly 60% of the florets produced viable seed, and Williams and Attwood (1971) maintain that viable seed is produced in most cases. Palmer (1958) reasons that in an area where one clone exists, seed production may be low, and where several clones exist, seed production may be high. Williams (1971a) found that quack grass seed collected in England germinated within about thirty days of sowing whereas 20% of samples from Canada remained dormant for up to three years.

Important factors in quack grass vs. crop competition

Shoot Competition

Thurston and Williams (1968) state that competition occurs for light, nutrients and water in a weed-crop situation. Cussans (1968) states that the most successful crop is the one that provides the greatest competition for light.

Palmer (1958) found that by reducing light intensity, on quack grass, to 8% of the noon day value, only a few small rhizomes developed and at 3% of the noon day value, no rhizomes were produced. Williams (1970a) shaded quack grass with a light filter allowing 46% of the day light intensity to pass through and found that shoot, rhizome and total dry weight decreased by 11, 51 and 36% respectively. He also simulated shading effects of a crop by placing shades over quack grass for the first half of the growing season and removing them for the remaining half season. Compared to the control for the first half season, the shaded plants had fewer shoots and spikes and rhizome production was reduced by half. With the shades removed, the quack grass recovered quickly and by the end of the growing season there was

no significant difference between treated and control plots, indicating the speed at which quack grass can recover during crop ripening when crop shading is decreased (Williams 1970a).

Root Competition

According to Welbank (1961a),major factors in root competition are,competition for water and nutrients, and the production of phytotoxins.

Using a test plant, *Impatiens parviflora* D.C. in competition with quack grass, Welbank (1961a) found that competition for water was slightly more important than competition for nitrogen. Further experiments on competition between quack grass and sugar beets for nitrogen and potassium (Welbank 1959a) and quack grass and radish for nitrogen and phosphorus (Welbank 1960) could all be explained by effects due primarily to nitrogen supply.

Phytotoxic materials have been extracted from quack grass by Kommedahl *et al.* (1959), Palmiter (1959) and Ohman and Kommedahl (1960) but according to Ohman and Kommedahl (1964) no one has isolated a compound which could reproduce the effects of the extracts. Leachates from live rhizomes have been tested and proven to have no phytotoxic activity (Welbank 1958), but rhizomes decaying under anaerobic (waterlogged) conditions produced a phytotoxin (Welbank 1959b, 1960, 1961b) which, according to Welbank (1960), could reduce rapeseed radicle extension by 55% compared to a 5-10% decrease caused by extracts after aerobic decomposition. Linscott and Harvey (1971) have found, in preliminary experiments, that evolution of ethylene from quack grass, especially the shoots, may be sufficient to cause

phytotoxic reactions in plants growing nearby.

Factors favoring crop competition with quack grass

Cultivation

According to Hakansson (1971), a combination of the effects of rhizome fragmentation, rhizome burial and crop competition should be used to bring about good cultural control of quack grass.

Vengris (1962), Turner (1968), and Hakansson (1971) reported that when cultivating quack grass, a combination of reduction of segment length and deep burial gave the greatest reduction in quack grass regrowth. Shoots regrowing from short (2.5-5 cm (1-2 inch)) segments buried 10-15 cm (4-6 inches) usually had insufficient food reserves to reach the surface (Vengris 1962 and Turner 1968). Shoots, from short segments that did emerge, however, were much weaker than shoots developing from long segments (Vengris 1962) hence able to provide very little competition with a healthy crop.

Seeding date and rate

Godel (1935) maintains that a crop should be seeded early, shallow and at increased rates combined with fertilization in order to smother weeds by producing a dense growth of crop roots and also abundant top growth to shade between the rows. Thurston and Williams (1968) state that crops sown at optimum depth may require two or three weeks to germinate and emerge. A paper by Cussans, reviewed by Thurston and Williams (1968) revealed that spring sown barley consistently emerged before quack grass. Within two to three weeks of seeding, 80-90% of the barley had emerged with only 10-40% of the quack grass appearing at this time. The slow development of quack grass after a pre-seeding

cultivation may have been caused by deep burial of rhizomes, and the time necessary to redevelop apical dominance (Chancellor in Thurston and Williams 1968). Williams (1969) found that early, medium and late seeding of spring wheat into a quack grass infestation reduced average total weights of quack grass by an average of 87, 64 and 26% respectively. The results of that experiment indicated that the weight of wheat was affected less by competition than was the weight of quack grass.

Mann and Barnes (1947, 1949) grew barley in competition with two perennial rhizome producing grasses *Holcus mollis* (L.) and *Agrostis gigantea* (Roth.). They found that barley sown thinly into an established stand of *Holcus* was totally eliminated whereas barley sown heavily into established stands of *Holcus* or *Agrostis* was only reduced by 50% and 25% respectively. According to Mann and Barnes (1947, 1949) the effects of barley on *Holcus* or *Agrostis* were greater than were the effects of the weeds on the crop.

Competition with quack grass by various crops

According to Pavlychenko and Harrington (1934) common annual crops can be arranged in descending order of competitive ability with annual weeds as follows: barley, rye, wheat, oats and flax.

Williams (1968a, 1970b) measured the growth of quack grass seedlings and spring wheat seedlings grown separately and found that in the first several weeks of growth, spring wheat, because of a larger seed, produced more top growth than quack grass e.g. quack grass 6.6 mg and wheat 70 mg. At the end of the growth period (5-6 months) the quack grass, once established, had dry weights comparable with those of wheat. Quack grass has a faster growth rate than wheat due to a

relatively larger leaf surface area, so according to Williams (1970b) would have the competitive advantage if it germinated before a crop. Williams (1971b) found that when quack grass seeds were sown into winter wheat, spring wheat, or spring barley, the resulting quack grass was equally suppressed by each crop. However, in plots fertilized with nitrogen, barley developed a larger leaf surface area and competed more successfully against the quack grass than did the other crops. He also tested the effects of barley or field beans with or without undersown ryegrass or clover on quack grass interseeded in the crops four days after crop seeding. The undersown crops increased the extent of quack grass suppression in both barley and beans but barley undersown with clover was the most effective. Barley alone, was also more effective in suppressing quack grass than field beans alone (Williams 1971b).

Cussans (1968, 1970), Barnard and Dyke (1970) and Dyke and Barnard (1971) found in field experiments including barley and field beans, that barley was also considerably more effective in competing with older well established quack grass than were field beans. Cussans (1970) planted wheat, barley and field beans into two different densities of quack grass e.g. low density (45 shoots per 0.83 sq m) (45 per yd^2)) and high density (185 shoots per 0.83 sq m (185 per yd^2)). Beans suffered losses of 43% in the low density infestation and 79% in the high density infestation. The cereals on the other hand, were unaffected by the low density population and suffered a 20% loss in the high density quack grass. He suggested that the crop least affected by quack grass was most effective in decreasing the weed's development. According to Cussans (1968), weights of quack grass in bean plots were

twice as high as quack grass in barley plots because of new rhizome growth induced by greater light penetration through bean foliage. There was almost no new quack grass rhizome growth in barley. Wheat, at anthesis, allowed only 10% of the visible light to reach the earth's surface (Thorne in Thurston and Williams 1968) and such low light intensity, according to Palmer (1958), is hardly sufficient for rhizome development. Barnard and Dyke (1970) using barley, and Dyke and Barnard (1971) using barley and beans undersown to ryegrass or clover found that undersown crops were very efficient in reducing quack grass development. Cussans (1972), in a two year attempt to reduce quack grass growth during the crop ripening stage and post harvest, planted barley undersown to Italian ryegrass or red clover. He also used white mustard and rapeseed (*Brassica campestris* L. and *Brassica napus* L.) as oversown crops. He found that barley oversown to ryegrass caused the greatest reduction in quack grass, but did allow some increases in rhizome development near the end of the experiment. A substantial loss in barley yield was also recorded. The oversown crops had considerable effect on quack grass growth with *Brassica napus* L. causing 30-40% reduction over the controls. Cussans (1972) suggests that because of possible crop yield loss, the benefit of underseeded crops in questionable. Lowe and Buchholtz (1952) were successful in using heavy seedings of oats or sunflowers to reduce quack grass infestations by 60%. Corns and Gupta (1971) found that winter rye in competition with quack grass reduced the quack grass forage weight by 92% of control and rhizome dry weight by 80% of control.

The foregoing selections from literature concerning quack grass

illustrate its strong ability to survive because of both seed production and vigorous vegetative propagation from rhizomes. Regrowth from rhizomes presents the main agronomic problem with regard to established stands. Results of tillage and cropping practices have shown considerable differences associated with variable environmental factors. Of these, shading by competing crops is obviously of major importance in weakening quack grass. In the work cited above, grasses (cereals) were more effective competitors than such broad leaved annuals as beans. This and other aspects of crop competition, however, seem to require further attention especially under various local conditions of soil, climate and farm practice. With this view the present investigation included certain annual cereal crops as well as broad leaved species, rapeseed and buckwheat.

Physiology of *Agropyron repens* L. in relation to herbicidal control

According to Palmer, in Sagar (1960) the life of rhizomes is about three years. The older rhizomes generally become metabolically inactive and the buds become dormant which leads to poor translocation activity. A herbicide in such a system could therefore then fail to reach the dormant buds in lethal quantities (Sagar 1960). He maintains that the breaking up of rhizomes by cultivation prior to spraying stimulates metabolic activity, bud and shoot development and facilitates herbicide translocation because of shorter rhizomes. He reasons that the best time to spray quack grass with herbicides is when use of metabolites below ground is highest. This time follows spring quack grass development from stored rhizome reserves, which leads to downward translocation of photosynthate that supports cell division and further rhizome production.

General recommendations for control of quack grass

The importance of quack grass as a weed problem in Alberta and recommended control practices involving cultivation, cropping and herbicides are outlined in a bulletin published by the Alberta Department of Agriculture (Carder 1969). The Research Appraisal Report of the Canada Weed Committee (Canada Weed Committee 1971, 1972) also summarizes current control measures considered to be most effective. Currently recommended herbicides have major limitations for agronomic use. TCA (trichloroacetic acid), dalapon and amino triazole may have residual phytotoxic effects in the soil for at least several months while sodium chlorate, monuron, atrazine and bromacil for example, may have residual effects lasting a year or more. They are therefore unsuitable for use in crop production except in special cases involving small patches of the weed. Another herbicide, paraquat, is effective for rapid top-killing of quack grass and is immediately inactivated by the soil but since this chemical is not translocated appreciably to root systems, quack grass regrowth is not prevented.

Since all the control measures used for quack grass control in crop production are less consistently effective and more costly than is desirable, there is clearly a need for better methods to solve this problem. The new experimental herbicide glyphosate may provide a very important part of the solution with regard to control of quack grass and certain other troublesome weeds on crop land.

The properties and mode of action of glyphosate

Glyphosate, (*N*-(phosphonomethyl)glycine) recently made available for experimental purposes, is a post emergent foliar applied herbicide

which, unlike paraquat, is actively translocated from shoots to underground rhizomes (Monsanto 1973). The herbicide is formulated as an isopropylamine salt (Monsanto 1973), monosodium salt or as the mono-(dimethylamine) salt (Baird and Begman 1972) and is effective for use on many annual, biennial and perennial broadleafed and grassy weeds (listed in Monsanto 1973). The treatment rates from .5 to 4.2 kg/ha a.e. (.45 to 3.75 lbs/A) are used with the lower rates for control of annuals and the higher rates for perennials (Monsanto 1973). Studies on translocation of glyphosate in Canada thistle (*Cirsium arvense* (L.) Scop.) (Gottrup 1974) show that this herbicide translocates from foliage treated plants to connected untreated plants along the roots. In some cases, however, some of the shoots along the same root were apparently by-passed by the glyphosate.

Jaworski (1972) suggests that glyphosate "interferes with the biosynthesis of phenylalanine and, more specifically, with the metabolism of chorismic acid in the aromatic amino acid biosynthetic pathway."

Evidence from the manufacturer indicates that glyphosate is rapidly inactivated in the soil under field conditions. Therefore the promising herbicidal efficiency of glyphosate and its lack of toxic residues indicate potential excellent concurrent quack grass control and crop production.

Quackgrass control using glyphosate

Since glyphosate is non-selective its use in agronomic cropping systems involves spraying the weed before seeding or emergence of the crop. The present author's research commenced in 1972 and

represents original work in this regard. Meanwhile there have been widespread additional investigations including those referred to here.

Phatak (1972b, 1973a) sprayed quack grass at the 5-6 leaf stage with 0.56 (0.5) 1.12 (1), 1.68 (1.5), and 2.24 (2) kg/ha (lb/A) glyphosate and then mowed the plots to 6.35 cm (2.5 inches) height on various selected dates after spraying. The control of quack grass mowed three days after spraying was comparable to the control of quack grass on plots mowed after longer spray-mow intervals (Phatak 1973a). He indicated that 0.56 kg/ha (0.5 lb/A) was insufficient to provide acceptable control. The plots that were not mowed after spraying had the best grass control.

Bandeen (1973a) found that the amount of control of quack grass by 1.12 (1), 1.68 (1.5), and 2.24 (2) kg/ha (lbs/A) glyphosate was nearly equal for each rate and that there was little difference in extent of control by leaving the spray-tillage interval longer than three days. Brown *et al.* (1973) after using the above rates of glyphosate, recorded increasing levels of control of 86%, 95% and 98% from the three dosages. His results indicate better quack grass control was realized if the spray-till interval was greater than seven days and that rototilling was better than plowing. Friesen (1972) maintains that as the spray-tillage interval increases to four weeks, less quack grass regrowth occurs. This may conceivably be due to greater combined effect of herbicide and subsequent tillage after some regrowth has commenced during such a prolonged period. Phatak (1973b) sprayed glyphosate (5-6 leaf stage) at 0.56 (0.5), 1.12 (1), 1.68 (1.5) and 2.24 (2) kg/ha (lbs/A) on two sites having rhizome

densities of 186 per 0.09 sq m (186 per sq ft) 237 per 0.09 sq m (237 per sq ft). All of the rates controlled the quack grass in the low density sites but only the higher rates provided satisfactory control for the high density sites.

Phatak (1972a) sprayed quack grass with 0.56 (0.5), 1.12 (1.0), 1.68 (1.5), and 2.24 (2.0) kg/ha (lbs/A) glyphosate on quack grass in the 1-2, 2-3, and 5-6 leaf stage, flowering and seeding stages. Glyphosate controlled the quack grass at the various growth stages with the exception that 0.5 lb/A was not very effective at the 1-2 and 2-3 leaf stages. Darwent (1973) supports these data to the extent that spring sprays of 2.24 kg/ha (2 lbs/A) or 3.36 kg/ha (3 lbs/A) glyphosate on quack grass in early shot blade, late shot blade and heading and flowering all resulted in the same amount of control. For fall applications of glyphosate, the best date, according to Bandeen and Rioux (1973c) was a mid-September treatment which proved better than either mid-October or mid-November treatments. Bandeen and Rioux (1973a,b), using rates of glyphosate from 0.85 kg/ha (0.75 lbs/A) to 3.36 kg/ha (3 lbs/A) for spring or fall applications found that spring applications were superior to fall applications. Split-applications in fall and spring appeared no better than a single fall application.

<u>Glyphosate and cropping</u>

Friesen (1972,1973) sprayed quack grass with 1.12 (1), 2.24 (2), 3.36 (3) kg/ha (lbs/A) glyphosate and at subsequent one week intervals, cultivated and planted barley. Glyphosate, in 1973, destroyed at least 90% of the quack grass. The barley yields, in some cases, were

triple that of the controls. No herbicide residual damage to barley was reported. Bandeen (1973d) applied glyphosate (1.12 (1), 1.68 (1.5) and 2.46 (2.2) kg/ha (lbs/A)) to quack grass in the 2-3 leaf stage, plowed and seeded winter wheat eighteen days later. Wheat yield in sprayed plots was about four times as much as that of the weedy control. No herbicide damage to the winter wheat was reported. Bandeen (1973 b,c) used combinations of glyphosate and other herbicides for quack grass control in field corn and soybeans and also reported no herbicidal damage to either crop.

Abstracts on some of the present author's research appear in Research Report of the Canada Weed Committee, Western Section (Valgardson and Corns 1972, 1973). Following is a more detailed report on various crops, tillage and herbicide treatments on densely infested quack grass land. This work enables some separation of the competitive effects of the crops from the combined effects of spraying and cropping on quack grass and crop yields.

I. GREENHOUSE EXPERIMENTS

A. Materials and Methods

1. Glyphosate translocation in rhizomes.

a. Effects of spraying glyphosate on single shoots on short rhizomes vs. several shoots on long rhizomes

A duplicate randomized experiment was established in the greenhouse to gain some indication of the relative efficiency of glyphosate treatments on growth which may occur under field conditions after limited or extensive tillage fragmentation of rhizomes. Rhizomes, collected in the fall of 1973 from a clonal population developed at the University of Alberta farm, Ellerslie, were stored in plastic bags in a cold room at 1-3° for later use. On October 19, 1973, rhizomes, uniform in length (36 cm-46 cm) and thickness, were prepared for germination from the cold room stock. They were germinated by placing them between layers of damp paper toweling and plastic, covering them with heavy paper to exclude light, and incubating them in a greenhouse at 20°C. Eight days later when there were five to seven shoots, 3-5 cm long, per rhizome, five rhizomes were planted 3 cm deep in each of twelve flats (30 x 46 x 8 cm) containing 3:2:1 (soil:peatmoss:sand) soil mix. By November 5, the shoots had grown to 10-20 cm and the rhizomes in six flats were then cut into sections mid-way between each shoot (20 ± 4 shoots per flat) and the remaining six flats (20 ± 4 shoots per flat) were left with rhizomes intact. On November 10, glyphosate sprays of 0.56 kg/ha (0.5 lb/A) and 1.12 kg/ha (1 lb/A) a.e. in 281 l/ha (25 gal/A) water, were applied from a bottle attached to a spray head and an aerosol-type propellant

container. Two flats each, of rhizome sections and of intact rhizomes, were sprayed leaving two boxes of each type for controls. Watering was delayed for twenty-four hours to prevent washing the herbicide from the foliage. For the following sixty-five days the flats remained in the greenhouse at about 20°C with a light intensity of 400-600 ft cdles, and supplementary lighting for fifteen hours per day. They were watered twice daily and were given a liquid fertilizer (20-20-20) once a week. Harvest data consisted of shoot fresh weights and rhizome fresh weights per flat as well as number of surviving shoots per flat.

b. Effects on the center shoot of long rhizomes from glyphosate sprays to both end shoots

General procedure applicable to this and to ensuing experiments in the series of greenhouse experiments to determine the extent of glyphosate translocation in long quack grass rhizomes was as follows. In the fall, rhizomes were gathered from the Saramaga farm (1972) or Ellerslie farm (1973), put in plastic bags, and stored at 1-3°C. Rhizomes 36-46 cm long were prepared for germination according to the procedure for experiment 1a. When their shoots had grown to 2-4 cm all but three of the shoots (one on each end and one in the center) were broken off leaving shoots separated by 1-3 nodes. Since the nodal bracts or scale leaves, on rhizomes, point away from the parent plant, this criterion was used at planting time to orient all the rhizomes in the same direction. Sprays on the end or center shoots could then be applied to obtain information on relative directional translocation effects on the other unsprayed shoots along the rhizome. The rhizomes were planted 3-4 cm deep in flats (30 x 46 x

8 cm) containing 3:2:1 soil mix. The flats were then transferred to a greenhouse at 20°C with a light intensity of 400-660 ft cdles in winter and 1000-1600 ft cdles in spring and fall. Supplemental lighting was provided for fifteen hours per day. When shoot growth had reached a suitable size for spraying the shoots not receiving glyphosate treatment were covered with plastic and the flats were then sprayed in 0.37 sq m areas with the assigned dosage of glyphosate in 281 l/ha (25 gal/A) water. Sprays were applied from a bottle attached to a spray head and an aerosol-type container. The flats were watered twice daily following a twenty-four hour delay after spraying, and a liquid nutrient mixture (20-20-20) was applied once a week. Following are details of the experiment involving glyphosate applied to both end shoots of long rhizomes.

A triplicate randomized experiment was established in the greenhouse with three treatments (check, 1.12 kg/ha (1 lb/A), 2.24 kg/ha (2 lb/A) a.e. glyphosate). Rhizomes collected in 1972 were prepared for germination on January 7, 1973 in accordance with the general procedure outlined under 1b. Nine days later when the rhizomes had germinated, they were planted ten to a flat. On February 9, the shoots growing on the tip-ends (as opposed to parent-ends) were clipped back to 15 cm because of excess growth, due to apical dominance, over that of the two other shoots on each rhizome. Three days later, when all the quack grass shoots had grown to 20 cm, the center shoots were covered with plastic and the shoots on both ends, except those of controls, were exposed to 1.12 kg/ha (1 lb/A) or 2.24 kg/ha (2 lb/A) a.e. glyphosate within an area 0.37 m. Observations were

made until harvest on March 6. Five rhizomes, chosen at random from each flat, were used for obtaining data on the center shoot area of the rhizomes. The data included: height of shoots, number of center shoots per flat, length and number of new rhizomes produced, and fresh and dry weights of both shoots and new rhizomes taken together. The numbers of surviving end shoots, per flat, were also recorded.

c. Effects on end shoots of long rhizomes from glyphosate sprays applied to the center shoot

The effects, on the end shoots, of glyphosate sprays applied to the center shoots were tested in two (c-1 and c-2) triplicate randomized experiments each with three treatments. Rhizomes collected in 1972 were prepared for germination on February 7, 1973 (c-1) and February 23 (c-2) in accordance with the general procedure outlined under 1b. Two weeks later the rhizomes were planted ten to a flat (c-1 and c-2). On March 14 the tip-end shoots of c-1 were clipped back to 15 cm to even the growth with other shoots along the rhizome and shoots of c-2 were left untouched. When the quack grass had grown to about 20 cm, March 20 (c-1) and March 30 (c-2), the end shoots were covered with plastic and, except for the controls, the flats were sprayed in 0.37 sq m areas with 1.12 kg/ha (1 lb/A) or 2.24 (2 lb/A) a.e. glyphosate (c-2, c-2). Experiment c-1 was accidentally watered two to three hours after spraying. Observations were made until harvest on April 3 (c-1) and April 12 (c-2). Five rhizomes, chosen at random from each flat, were used for collecting data for shoots on each end of the rhizomes. The data (the sum of five readings per flat) included: shoot height, number of shoots, length of new rhizome

growth, and fresh and dry weights of both shoots and new rhizomes together. For c-1, the mean condition (scores 0-9) for the center shoots were tabulated and for c-2 the mean condition (scores 0-9) for center shoots as well as end shoots were taken. (Score 0-9 is a measure of the effects of the herbicide on plants with 0 being a healthy plant and 9 being completely dead).

d. Effects on other shoots along the rhizome from glyphosate sprays applied to either the parent-end or tip-end shoots

Two randomized experiments with three treatments (check, 0.56 kg/ha (0.5 lb/A), 1.12 kg/ha (1 lb/A) and three repeats were established in the greenhouse. In one experiment the parent-end shoots were treated with glyphosate and in the other experiment the tip-end shoots were treated. Rhizomes collected in 1973 were prepared for germination on January 16, 1974 in accordance with the procedure outlined in lb. One week later the rhizomes were planted six to a flat. Shoots on several rhizomes failed to grow and on January 28 the rhizomes were thinned to three per flat. On February 5, the tip-end shoots were clipped back to 15 cm to even the growth with other shoots along the rhizome. Three days later when the shoot growth was 20-25 cm, the center shoots and end shoots opposite the one to be sprayed were covered with plastic and, except for controls, the flats were sprayed with the appropriate dosages of glyphosate in 0.37 sq m areas. Observations were made until harvest on January 22, 1974. The data were taken on the three shoots (parent-end, center, and tip-end) on each rhizome for each of three rhizomes per flat. The data included:

shoot height, shoot count, length of new rhizome growth, fresh weight and mean score (0-9) of the shoots for each experiment.

2. The effects on crop seedlings of glyphosate sprayed on the soil.

a. <u>General procedures</u>

A series of greenhouse experiments was established to test the effects of soil applied glyphosate on crops sown prior to spraying. Completely randomized experiments were set up having four replications with a check, 2.24 (2), 4.48 (4), 6.72 (6), and 8.96 (8) kg/ha (lb/A) glyphosate treatments. Each flat (12 x 17 x 8 cm), containing 3:2:1 soil mix, was sown with thirty seeds (barley, buckwheat, oats, rapeseed or rye), saturated with water, and then set aside to drain. Within twenty-four hours of seeding, the soil surface of all flats except unsprayed controls was sprayed with glyphosate from a bottle attached to a spray head and an aerosol-type container, at 281 l/ha (25 gal/A) water. The flats were then transferred to a growth chamber at 20°C and illuminated for sixteen hours per day at a light intensity of 1300-1500 ft cdles. Following a twenty-four hour delay after spraying, the flats were watered twice daily and a liquid fertilizer 20-20-20 was applied once a week. Observations were made from the date of emergence of the crop seeds to harvest.

Following are details of experiments involving the general procedure outlined above.

b. <u>Preliminary test on barley, oats, rye, buckwheat and rapeseed</u>

A preliminary experiment was set up to test glyphosate on

barley, oats, rye, buckwheat and rapeseed on June 15, 1973. The crops were sown on June 15 with rapeseed at twenty seeds per flat and the remaining crops at thirty seeds per flat. Following a drainage period of about two hours, the flats were sprayed. On June 25, the crops were harvested for the following data recorded per flat: mean shoot height, fresh and dry weights of shoots, number of tillers (barley and rye), number of plants having true leaves (buckwheat) and plants having no true leaves (rapeseed).

c. Rye

Rye, seeded 1 cm deep on November 1, 1973, was sprayed on November 2. The plants emerged on November 5. Twelve days later the experiment was harvested for records, per flat, of mean shoot height, number of tillers, and fresh weight.

d-1. Buckwheat

Buckwheat was seeded 1-1½ cm deep on October 18, 1973 and sprayed on October 19. The seedlings emerged on October 23. Observations were made on the plants until harvest on November 7 for records, per flat, of mean plant height, fresh weight (shoots), number of plants without true leaves and number of plants.

d-2. Buckwheat

Since buckwheat germination was very poor,another experiment was undertaken using selected pre-germinated seed. On November 9, 1973, seed was placed between layers of damp paper toweling and plastic and incubated in a greenhouse at 20 C for germination. Three days later when the seedling radicle length was 1-2 cm, thirty seedlings were sown per flat. Six hours later the flats were sprayed with the

appropriate dosages of glyphosate. The buckwheat emerged on November 15 and was observed until harvest on December 4. The plants were harvested for data, per flat, for mean shoot height, shoot number, fresh weight of shoots, and plants having fewer than three true leaves.

e-1. Rapeseed

Rapeseed was sown at 0.75 cm deep on November 8, 1973, and was sprayed on November 9. The seedlings emerged four days later. The flats were harvested on December 3 for data, per flat, concerning mean shoot height, number of plants, and fresh weight.

e-2. Rapeseed

Rapeseed was sown 0.75 cm deep on January 7, 1974, and was sprayed on January 8. The rapeseed seedlings emerged four days later and were observed as they grew, to the flowering stage. On February 11, 1974, the flats were harvested for data, per flat, concerning number of plants, mean shoot height, plants greater than 30 cm and having flowers, plants less than 30 cm and having flowers, and fresh weight.

e-3. Rapeseed

Glyphosate was sprayed on the soil at the dosages outlined in experiment 2a on January 8, 1974, four days prior to seeding rapeseed 0.75 cm deep. The rapeseed emerged on January 17 and was observed until harvest on February 6. Data, per flat, were taken for number of plants, mean shoot height, and fresh weight.

B. Results, Discussion and Conclusions

1. Glyphosate translocation in rhizomes.

a. Effects of spraying glyphosate on single shoots on short rhizomes vs. several shoots on long rhizomes

Glyphosate injury symptoms on shoots, shown by slight chlorosis and general lack of vigor, became evident on shoots of both long and short rhizomes within two to three days after spraying 1.12 kg/ha (1 lb/A) and three to four days of spraying 0.56 kg/ha (0.5 lb/A). Chlorosis, beginning at the leaf tips of plants sprayed at 1.12 kg/ha, progressed until nine to ten days after spraying at which time most of the shoots were dead. Herbicide injury progressed more slowly and less effectively on shoots sprayed at 0.56 kg/ha causing death to approximately half of the shoots within twelve days of spraying. Some shoots that survived 0.56 kg/ha glyphosate treatment stopped growing but produced a profusion of shoots at the base of the primary shoot (figure 1).

For the final analysis, the data for the two rates of glyphosate (0.56 kg/ha and 1.12 kg/ha) were pooled within each of the long and short rhizome treatments (table 1). There were no significant differences between the effects of glyphosate applied to shoots on short rhizomes in comparison with responses to treatments of shoots on long rhizomes. Such results suggest that cultivation and shoot regeneration prior to spraying may not result in any advantage over spraying a quack grass infestation having intact rhizomes.

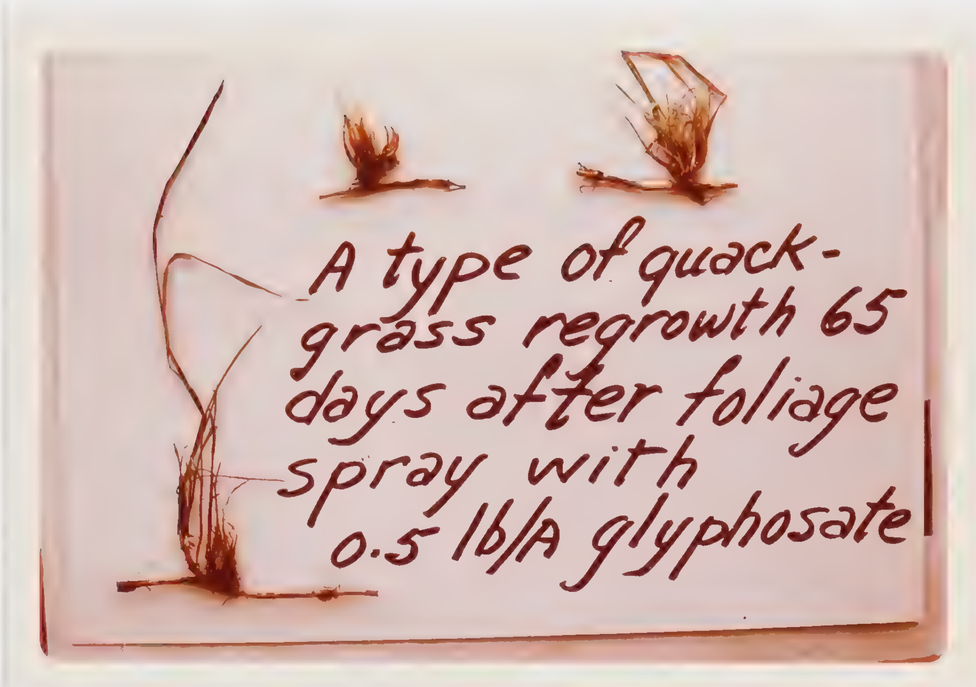

Figure 1. Sublethal effects of glyphosate on quack grass. The profuse development of shoots occurred at the base of main shoots within 65 days after applications of 0.56 kg/ha of the herbicide.

Table 1. Effects of glyphosate sprayed on one shoot on short rhizomes compared with equivalent sprays on several shoots on long rhizomes 65 days after spraying. (Means of 4 replications, 2 sprayed at 0.56 kg/ha (0.5 lb/A) 2 sprayed at 1.12 kg/ha (1.0 lb/A) glyphosate).

Treatment	Number of Surviving Shoots	Fresh wt. of Forage (g)	Fresh wt. of New Rhizomes (g)
Control	141 a*	241.0 a	112.8 a
Sprayed (Shoots from short rhizomes)	7 b	9.7 b	1.3 b
Sprayed (Shoots from long rhizomes)	1 b	3.0 b	0.8 b

*means followed by the same letter are not significantly different at the 1% level using Duncan's Multiple Range Test (Duncan 1955).

b. Effects on the center shoots of long rhizomes from glyphosate sprayed on both end shoots

Within two days of glyphosate application in this experiment, the treated shoots were lighter in color than those of the control treatments. Within the following two days the treated plants became more chlorotic, especially at the leaf tips, and began to lose turgor. Effects on the shoots sprayed at 2.24 kg/ha (2 lb/A) were more advanced than on those treated at 1.12 kg/ha (1 lb/A). Six days after spraying the end shoots, mild chlorosis and some leaf twisting or curling were evident on the center shoot. At this time the end shoots were very chlorotic and some were dying back from the tips. Ten days after spraying, most end shoots treated at 2.24 kg/ha were dead and most shoots treated at 1.12 kg/ha were yellow-green in color but still living. At this time the center shoots had lost turgor and were pale green to yellow in color. The results of the experiment (table 2, showing only variables which are significantly different) indicate that both dosages of glyphosate used in this experiment were equally effective in producing the significant effects of translocation along the rhizome from sprayed to unsprayed shoots.

c. Effects on end shoots of long rhizomes, from glyphosate sprayed on the center shoot

Quack grass growing in experiment c-1 (accidentally watered 2-3 hr after spraying) did not show the symptoms of glyphosate injury for approximately five days after spray application. The leaves became mildly chlorotic and further symptoms developed slowly until harvest. At that time the sprayed shoots, although alive, were

Table 2. Effects on growth at the center shoot of rhizomes 21 days after spraying single shoots on both ends of the rhizome with glyphosate. (Means of 3 replications each involving the sum of data from 5 rhizomes)

Treatment glyphosate kg/ha (lb/A)	Length of new rhizomes at the center shoot (cm)	Fresh weight the center shoot (g)	Dry weight at the center shoot (g)	No. of live shoots on sprayed ends
0 (0)	83 a*	26.7 a	4.4 a	2.9 a
1.12 (1)	7 b	5.9 b	1.6 b	0.2 b
2.24 (2)	3 b	5.3 b	1.5 b	0.1 b

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan 1955).

chlorotic and lacked sufficient turgor to stand upright. It was difficult to observe whether glyphosate was translocated to either the parent-end or the tip-end shoots with greater intensity since the herbicidal symptoms were slow in developing and very variable. However, the final analysis of results (table 3 - showing only variables that are significantly different) indicate that the length of new rhizome growth was substantially reduced at both ends of the rhizome but was not significantly different between dosages applied. This suggests that

Table 3. Effects on growth of shoots at both ends of rhizomes 14 days after spraying a single center shoot with glyphosate. (Means of 3 replications each involving the sum of data from 5 rhizomes).

Treatment kg/ha (lb/A)	Length of new rhizomes (parent-end) (cm)	Length of new rhizomes (tip-end) (cm)
0	76 a*	67 a
1.12 (1)	36.6 b	23 b
2.24 (2)	17.3 b	22.6 b

*Means followed by the same letter are not significantly different at the 1% level using Duncan's Multiple Range Test (Duncan 1955).

glyphosate was translocated in both directions along the rhizome but does not indicate a predominant direction of flow.

In experiment c-2 the treated quack grass shoots developed symptoms of glyphosate injury two to three days after spraying, and within ten days after spraying 2.24 kg/ha (2 lb/A) glyphosate, some

shoots were dead except for some green areas at the base of the stems. The effects of glyphosate at 1.12 kg/ha (1 lb/A) developed somewhat more slowly but were apparently ultimately as great as from the higher dosage (table 4-showing only variables which are significantly different). Parent-end and tip-end shoots, eight to nine days after spraying, both began to develop a chlorotic appearance which progressed slowly and apparently equally on both unsprayed shoots on each rhizome. The appearance of herbicide injury in both end shoots on the rhizomes confirms the indication in experiment c-1 that glyphosate was translocated in both directions along the rhizome. In addition, the results of experiment c-2 (table 4) consistently show significant differences between the variables at the tip-end shoot of the control and glyphosate treated rhizomes, but such differences did not exist in comparisons between parent-end shoots of control and glyphosate treated rhizomes. The data recorded from the parent-end shoots of treated rhizomes were, however, somewhat comparable to the data for the tip-end shoots of treated rhizomes. They were, however, more variable, hence resulting in the lack of significant differences between respective control and glyphosate treatments for parent-end shoots. This suggests that glyphosate may tend to accompany metabolites flowing predominantly in the direction of the tip of the rhizome.

Table 4. Effects on growth of shoots at both ends of rhizomes*** 13 days after spraying a single center shoot with glyphosate. (Means of 3 replications each involving the sum of data from 5 rhizomes).

Treatment glyphosate kg/ha (lb/A)	Shoot height (tip-end)(cm)	Length of new rhizome growth (tip-end)(cm)	Shoot fresh weight (tip-end) (g)	Shoot dry weight (tip-end) (g)	mean score of 5 shoots per flat (tip-end) (0-9)	mean score of 5 shoots per flat centre shoot (0-9)
0 (0)	161 a*	6.1 a*	10.8 a**	2.6 a*	0 a**	0 a**
1.12 (1)	142 b	16 b	5.3 b	1.7 b	2.8 b	6.8 b
2.24 (2)	131 b	4 b	4.6 b	1.2 c	5.8 c	7.2 b

Means followed by the same letter are not significantly different using Duncan's Multiple Range Test (Duncan 1955).

*significant at 5%

**significant at 1%

***significant differences between treated and control material did not occur at the parent-ends of the rhizomes

d. Effects on other shoots along the rhizome from glyphosate sprays applied to shoots on either the parent-end or the tip-end shoots

Glyphosate injury symptoms on sprayed shoots were comparable to those of previous experiments on long rhizomes. Within two to three days after spray application, shoots sprayed at 1.12 kg/ha (1 lb/A) began to develop very slight chlorosis at the leaf tips and the plants appeared to lack vigor. Within nine to eleven days most of these shoots were dead. Shoots treated with 0.56 kg/ha (.5 lb/A) glyphosate were slower to develop herbicidal injury symptoms and only two shoots which were on the parent-end of the long rhizomes were dead after two weeks. Symptoms of sublethal glyphosate injury as a result of translocation to unsprayed shoots are shown in figures 1 and 2.

Herbicide injury symptoms on shoots at the center and on the ends opposite the sprayed shoots appeared between six and eight days after spray application. There appeared to be no difference in the intensity of glyphosate injury in unsprayed shoots or in the length of time until it occurred, whether the parent or tip-end shoots of these long rhizomes received glyphosate treatment. There also did not seem to be a uniform progression of symptoms of glyphosate injury in shoots along the rhizome. In some cases both the center and unsprayed end shoots were equally affected by the herbicide and in other instances the unsprayed end shoots were affected more than the center shoot.

The results of the experiments shown in the tables (glyphosate applied to parent-ends, table 5, and glyphosate applied to tip-ends, table 6) give only data for the variables which are significant and

Figure 2. Sublethal effects of glyphosate translocation to the centre shoot on a quack grass rhizome, within 14 days after spraying the shoot on the left with 0.56 kg/ha of the herbicide. Malformation of new leaf development is evident.

Table 5. Effects on growth at the parent-end (1), center (2), and tip-end (3) shoots of rhizomes 14 days after spraying single shoots at the parent-end. (Means of 3 replications each involving the sum of data from 3 rhizomes).

Treatment		Shoot height (cm)		Shoot count	Length of new rhizomes (cm)		Fresh weight (g)			Mean score of 3 shoots per flat (0-9)		
kg/ha	lb/A	1	3	1	1	3	1	2	3	1	2	3
0	(0)	125 a**	146 a**	6 a*	12 a**	15 a**	7.0 a**	9.8 a**	9.8 a*	0 a**	0 a**	0 a**
0.56	(0.5)	99 b	102 b	3 b	1 b	2 b	1.7 b	6.0 ab	4.5 b	6.1 b	3.7 b	4.3 b
1.68	(1.5)	97 b	114 b	4 b	1 b	2 b	1.4 b	3.0 b	4.0 b	4.36 b	5.7 b	5.3 b

Means followed by the same letter are not significantly different using Duncan's Multiple Range Test (Duncan 1955).

*significant at 5%

**significant at 1%

Table 6. Effects on growth at the parent-end (1), center (2), and tip-end (3) shoots of rhizomes 14 days after spraying single shoots at the tip-end. (Means of 3 replications each involving the sum of data from 3 rhizomes).

Treatment	Shoot height (cm)			Shoot count	Length of new rhizomes (cm)		Fresh weight (g)			Mean score of 3 shoots per flat (0-9)		
kg/ha lb/A	1	2	3	3	1	3	1	2	3	1	2	3
0 (0)	125a*	136a**	146a**	8.3a*	12a*	15a**	7.0a*	9.8a**	9.8a**	0a**	0a**	0a*
0.56 (0.5)	99 b	111 b	109ab	5.0 b	3 b	3 b	4.0 b	5.7 b	3.0 b	4.4 b	4.4 b	5.1 b
1.68 (1.5)	101 b	109 b	98 b	3.0 b	1 b	1 b	2.4 b	2.7 c	0.9 b	5.3 b	5.1 b	8.8 b

Means followed by the same letter are not significantly different using Duncan's Multiple Range Test (Duncan 1955).

*significant at 5%

**significant at 1%

again confirm that glyphosate was translocated in both directions along the rhizome. Since unsprayed shoots along the rhizomes were almost equally affected whether the sprayed shoots were on the parent-ends or on the tip-ends (figure 3), there seems no doubt that herbicidal sprays of glyphosate can readily result in translocation effects along the rhizomes in both directions. It has already been noted, however, that under the conditions of experiment c-2 there was some indication of greater movement of toxic chemical to the tip-ends of the rhizome. In view of the results of experiment d and the variability in experiment c-2, however, the evidence does not warrant any firm conclusions as to the predominant direction of flow of the toxic chemical.

2. The effects on certain crop seedlings of glyphosate sprayed on the soil.

(Note: Topic a was completed under "Materials and Methods"- General procedures.)

b. <u>Preliminary experiment on barley, oats, rye, buckwheat and rapeseed</u>

Soil applied glyphosate did not affect either the physical appearance, germination and emergence, or the subsequent growth of barley and oats.

Rye indicated the possibility of some growth promotion by the herbicide. There were some increases in fresh weights of rye in soil treated with the higher rates of glyphosate. However, because of some variability within this experiment another similar trial was established and is discussed under section c.

Buckwheat germination and emergence was poor and may have been

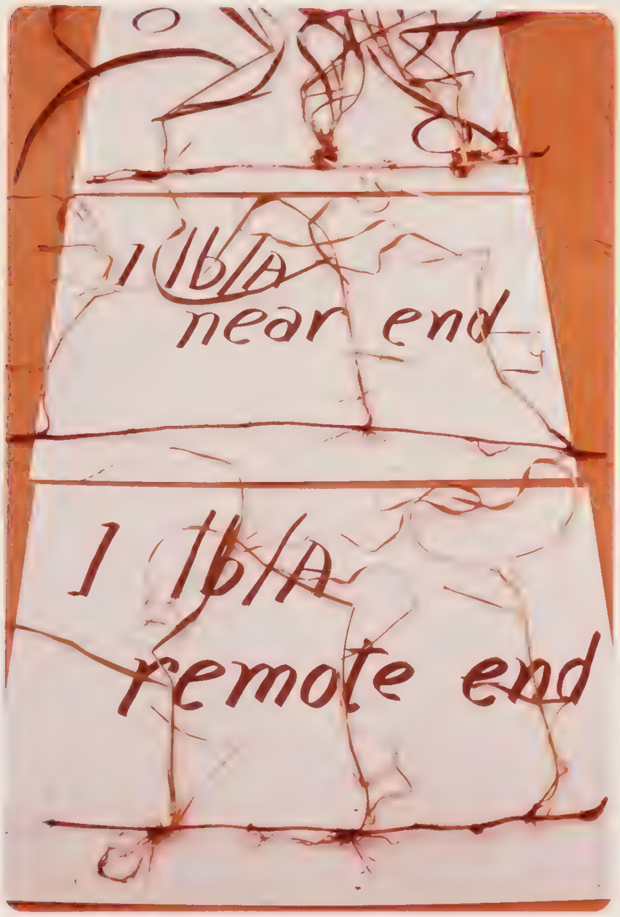

Figure 3. Glyphosate at 1.12 kg/ha, whether applied to the near end (parent-end) shoot or the remote end (tip-end) shoot, translocated along the rhizome in either direction affecting the unsprayed shoots along the rhizome. (Photo 14 days after spraying; control at top).

responsible for most of the variability within this experiment. Nevertheless, some herbicide damage was evident. Shoot height, fresh weight, and number of plants having true leaves were decreased by the 8.96 kg/ha (8 lb/A) rate of glyphosate. Further experiments will be discussed under section d.

Rapeseed was very sensitive to relatively high dosages of soil-applied glyphosate and the results of this experiment (b) will be discussed with the results of subsequent relevant experiments in section e.

c. Rye

The repeated experiment with rye following the preliminary test noted in section b, indicated no significant effects of glyphosate on mean shoot height, number of tillers or fresh weight of rye plants. The complete lack of glyphosate effect on rye plants in this experiment indicates that the results from the preliminary experiment suggesting stimulation by the herbicide were caused by the variability of growth, including controls, in the first experiment.

d. Buckwheat

Experiment d-1 was, as in the preliminary experiment on buckwheat, very variable due to poor seed germination. The herbicide damage, however, was again evident on the basis of the same criteria noted in the preliminary experiment.

The variability caused by poor seed germination was reduced by using pre-germinated seed in experiment d-2. There were no observable physical differences during the growth period but harvest data indicated some effect of the herbicide in reducing the height of buckwheat.

Thus in all of the growth chamber experiments with buckwheat, some herbicide damage was recorded by the higher dosages of glyphosate, but because of the variability they do not warrant any firm specific conclusions.

e. Rapeseed

Observations of the rapeseed experiments indicated that there were no immediate effects of the herbicide on germinating or emerging rapeseed seedlings. Within eight or nine days after seeding (4 or 5 days after emergence) (figure 4), however, the cotyledons of the plants growing in 4.48 (4), 6.72 (6) and 8.96 (8) kg/ha (lb/A) glyphosate treatments became dark green compared to light green of control plants. Ensuing growth in height and first true leaf development was retarded (expt. b, table 7, showing only variables which are significant) in the 6.72 and 8.96 kg/ha treatments. Some plants developed true leaves which appeared chlorotic and malformed and other plants had no true leaf development. Within two weeks after seeding time, the plants growing in the 0, 2.24, and 4.48 kg/ha treatments had developed the second and third true leaves and exhibited no physical differences from one another. By this time the plants growing in the 6.72 and 8.96 kg/ha treatments appeared to be overcoming the effects of the herbicide and some plants appeared to be normal. The rapeseed experiments (b and e-1, table 7 showing only variables which are significant) harvested at ten and twenty-five days after sowing also indicate that the rapeseed tended to overcome the effects of the herbicide. However, when rapeseed reached the stage of flower initiation (within 30 days of sowing, when plants were grown in the growth chamber) the plants growing

Figure 4. Effects of soil-applied glyphosate on emerging rapeseed. Note the stunted retarded development of the 4.48 kg/ha and 6.72 kg/ha treatments (on the right) compared to the control on the left.

Table 7. Effects of soil-applied glyphosate on subsequent growth of rapeseed (Mean of 4 replications each sown with 20 seeds (exp b) 30 seeds (exp 3-1).

Experiment b					Experiment e-1		
Rapeseed harvested 10 days after sowing and 9 days after glyphosate application					Rapeseed harvested 25 days after sowing and 24 days after glyphosate application		
Treatment glyphosate kg/ha	(lb/A)	Mean shoot height (cm)	Fresh wt. of shoots (g)	number of plants having no true leaves	Treatment glyphosate kg/ha	(lb/A)	Fresh weight of shoots (g)
0	(0)	4.9a*	4.5a	3.5a	0	(0)	58.3a*
2.24	(2)	5.3a	5.1a	1.5a	2.24	(2)	52.8a
4.48	(4)	4.3a	4.1a	2.5a	4.48	(4)	54.8a
6.72	(6)	2.8 b	1.5 b	6.8 b	6.72	(6)	39.2ab
8.96	(8)	2.4 b	1.2 b	7.5 b	8.96	(8)	30.5 b

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan 1955).

in soil treated with the higher dosages of glyphosates were again retarded (e-2, table 8, showing only significant variables).

Comparisons would have been even more satisfactory had it been feasible to secure data for the various growth responses of rapeseed at different stages of development within the same experiments.

Rapeseed grown in experiment e-3 did not show any of the physical effects of glyphosate injury observed in experiments b, e-1 and e-2. The final analysis (table 8 (e-3) showing only variables which are significant) indicates that the herbicide affected only the fresh weights.

In general the results of rapeseed experiments in the growth chamber indicate that this crop is sensitive to soil applied glyphosate, even when the herbicide is sprayed on the soil four days prior to seeding. The rates of glyphosate which caused consistent injury, however, are greater than those which would be used in the field. Field experiments using glyphosate on quack grass at 2.8 kg/ha (2.5 lb/A) two weeks prior to sowing rapeseed did not affect rapeseed plants at all.

Table 8. Effects of soil-applied glyphosate on subsequent growth of rapeseed (Mean of 4 replications each sown with 30 seeds).

Experiment e-2					Experiment e-3		
Rapeseed harvested 34 days after seeding and 33 days after glyphosate applications to the soil					Rapeseed sown 4 days after glyphosate application and harvested 29 days after seeding		
Treatment glyphosate kg/ha	(lb/A)	Mean shoot height (cm)	Plants flowering >30 cm	Plants flowering <30 cm	Treatment glyphosate kg/ha	(lb/A)	Fresh weight of shoots (g)
0	(0)	20 a*	4.0a	11.2a	0	(0)	36.3a*
2.24	(2)	18 a	3.5a	6.0 b	2.24	(2)	28.4 b
4.48	(4)	14 b	2.2 b	5.5 b	4.48	(4)	29.3 b
6.72	(6)	12.9 b	1.0 b	5.2 bc	6.72	(6)	27.1 b
8.96	(8)	13.2 b	0.7 b	2.7 c	8.96	(8)	26.3 b

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan 1955).

II. FIELD EXPERIMENTS

A. Materials and Methods

1. Glyphosate dosage experiments with or without cultivation.

a. Effects of various dosages of glyphosate on quack grass with or without cultivation

Two field experiments, one in 1972 (a-1) and one in 1973 (a-2), were established to test the effectiveness of various dosages of glyphosate on quack grass with or without cultivation after spraying. Duplicate randomized blocks with plots 3 x 3 m (a-1) and triplicate randomized blocks with plots 2.2 x 3 m (a-2) were laid out on peaty clay loam soil west of Edmonton (Saramaga farm). The plots for both experiments were on soil that had not been cropped the previous year and had developed a solid infestation of quack grass. Glyphosate (isopropylamine formulation - 3 lb a.e. per U.S. gallon was used in all experiments using glyphosate) sprays of 1.12 (1), 2.24 (2) and 3.36 (3) kg/ha (lb/A) in 281 l/ha (25 gal/A) water at 1.76 kg/sq cm (25 psi) were applied in July 15, 1972 (a-1) on quack grass regrowth of 20 cm height after a mowing three weeks previously, and on June 21, 1973 (a-2) on quack grass 26 cm tall in the 4 leaf stage. A rain shower occurred eight to ten hours after spraying experiment a-1 but conditions for spraying experiment a-2 were ideal with no rain falling within a day after spraying. In both experiments all of the sprayed quack grass top-growth was dead within two weeks except for some shoots in the 1.12 kg/ha (1 lb/A) plots (a-2). At that time half of each plot including some controls in a-1 and certain plots assigned for each treatment in a-2 were cultivated 13 cm deep with a rototiller. The

uncultivated portions of plots in a-1 and the uncultivated treatments in a-2 were left undisturbed until harvest. On September 28, 1972 a-1 and August 27, 1973 a-2, harvests for quack grass shoot counts, height and forage dry weights were taken from 0.85 m^2 quadrats. Rhizomes were sampled from quadrats 0.63 m^2, 15 cm deep.

b. <u>Effects of cultivation on quack grass before and or after the application of glyphosate</u>

An experiment, on peaty clay loam soil west of Edmonton (Saramaga farm), was established to test the effects of glyphosate on quack grass sprayed before or after cultivation and with or without subsequent cultivation. Plots 2 x 3 m with 61 cm continually roto-tilled borders were laid out in triplicate randomized blocks on soil solidly infested with quack grass in an area summerfallowed in 1970. The schedule of operations for this experiment is summarized in Table 9. Quack grass on D1 (Date 1) was 12 cm tall in the 2-3 leaf stage, and on D2 for treatments 3,4 and 6 was in late shot blade stage 68 cm tall. For treatments 1, 2 and 5 on D2, the quack grass regrowth (after cultivation on D1) was 23 cm tall at the 3-4 leaf stage. A rototiller, tilling 13 cm deep, was used on all plots scheduled for cultivation. Glyphosate at 2.8 kg/ha (2.5 lb/A) in 281 l/ha (25 gal/A) water at 1.76 kg/sq cm (25 psi) for all treatments (1, 2, 3 and 4) was sprayed on D2 under ideal conditions. By D3 all sprayed plots had complete top-killing, but plots cultivated on D2 had 5 cm regrowth. The plots were hand weeded during the 1972 and 1973 seasons to remove annual weed growth. Harvesting commenced on September 26, 1972 and on July 26 in 1973. Quack grass shoot counts, height and forage dry

Table 9. Schedule of Operations (section 1-b)

Treatment number	Date 1 (D1) May 8, 1972	Date 2 (D2) June 15, 1972	Date 3 (D3) June 27, 1972
1	Till	Spray	Leave
2	Till	Spray	Till
3	Leave	Spray	Leave
4	Leave	Spray	Till
5	Till	Till	Till
6	Leave	Till	Till
7	Leave	Leave	Leave

weights were taken from 0.85 m^2 quadrats, and rhizome samples were taken from 0.65 m^2 quadrats 15 cm deep.

c. Influence on quack grass of various periods of delay before removing top-growth after glyphosate application

A field experiment was established to determine the influence on quack grass survival of various periods of delay before removing top growth after spraying with glyphosate. A dense stand of quack grass (approx 900 shoots per m^2) growing in a Malmo clay-loam soil at Ellerslie farm was used for laying out the experiment in replicated blocks. This quack grass area had been planted with rhizomes in 1971. On July 23, 1973, when the quack grass was at advanced heading stage, glyphosate was applied at 1.7 kg/ha (1.5 lb/A) and 2.8 kg/ha (2.5 lb/A) in 281 l/ha (25 gal/A) water at 1.76 kg/sq cm (25 psi). About 2 cm of rain began to fall ten hours after spraying. Duplicate strips of quack grass 0.8 x 4.2 m for each rate were mowed about 1.5 cm above ground commencing one day after spraying and continuing with new strips each day until the ninth day. Since there was, by then, some yellowing but still no major visible injury, the remaining three cuttings were done on the eleventh, thirteenth and fifteenth days after spraying. By this latter time practically all the foliage treated with either dosage was dead. Unsprayed control strips were mowed one or eleven days after the spray date. On September 28, sixty-seven days after spraying, data for numbers of shoots, their height and fresh weight per 2.84 sq m strip sample were recorded for the sprayed plots. For the control plots 0.4 sq m quadrats were used and the results extrapolated to a 2.84 sq m area for comparisons with the sprayed plots.

2. Quack grass seedling competition with oats, rapeseed, buckwheat and winter rye.

A field experiment to determine the competitive effects of quack grass seedlings on oats, rapeseed, buckwheat and winter rye was conducted on summerfallowed Malmo clay loam soil at the University of Alberta farm, Ellerslie. The soil was disced on May 15, 1973 prior to seeding quack grass into plots 1.85 x 2.5 m replicated four times for each treatment. Fertilizer (16-20-0) at 112 kg/ha (100 lb/A) was then broadcast across the plot area and raked into the soil. The quack grass seeds, collected in the fall of 1972 and having 50% germination, were then sown on May 17 to a depth of 1 - 1.5 cm at 20 kg/ha (18 lb/A) viable seed. The quack grass was sown prior to the crops to favor establishment of the quack grass seedlings. On June 6 when the quack grass was 7 cm tall, the crops were sown between the rows of quack grass and also in plots containing no quack grass. Rates of seeding of the crops (adjusted to 100% viable seed) were as follows; Rodney oats, 91 kg/ha (2.4 lb/A); Polish rape 6.7 kg/ha (6 lb/A); Tokyo buckwheat, 65 kg/ha (1.2 bu/A); and Frontier winter rye 88 kg/ha (1.4 bu/A). Germination of the quack grass was patchy but sufficient to provide for selection of relatively uniform sample sites for harvest. Germination of the crops was uniform and excellent. Seasonal precipitation (May-September) amounted to 34 cm. The plots were hand weeded during the summer to remove annual weeds. During mid-August a frost damaged the tops of buckwheat, limiting its yield to forage. Harvesting took place on September 4 except for oats which matured thirteen days later. Quack grass and crop forage dry weight yields,

and crop seed yields were taken from 0.85 m^2 quadrats. Quack grass rhizome determinations were made from 0.63 m^2 quadrats 15 cm deep.

3. Crop competition with quack grass with and without glyphosate application.

   a. <u>Crop competition with quack grass with and without glyphosate application in 1972</u>

Crop competition with quack grass with and without glyphosate treatment before spring cultivation and seeding was tested in 1972 on two Edmonton area farms. One experiment, on a farm southeast of Edmonton (a-1 Ritchie farm), consisted of unreplicated paired plots (because of infested area limitation) on a sandy loam soil. The second experiment, on a farm west of Edmonton (a-2 Saramaga farm), consisted of triplicate randomized blocks on a peaty clay loam soil. Both farms had heavy continuous infestations of quack grass on grain crop land that had been summerfallowed two years previously. Quack grass populations were 1500 shoots per m^2 with 400 gm dry weight rhizomes per m^2, 15 cm deep. Plots 2 x 3 cm were set out with 61 cm continually rototilled borders to prevent quackgrass invasion. On May 19 (a-1) and May 20 (a-2) when the quack grass was 12-15 cm tall, 4-6 leaf stage, some plots were rototilled about 13 cm deep and others were sprayed with 2.8 kg/ha (2.5 lb/A) glyphosate in 281 l/ha (25 gal/A) water at 1.76 kg/sq cm (25 psi). No rain fell at either site within twenty-four or more hours after spraying. Ten days later, after top-killing was 100% in the sprayed plots, all of the plots except one of the sets of sprayed controls, were rototilled 13 cm deep prior to seeding. A garden seeder was used to seed Rodney oats (68.5 kg/ha)(1.8 bu/A),

Sangaste winter rye (113 kg/ha) (1.8 bu/A), Tokyo buckwheat (97 kg/ha) (1.8 bu/A), Gateway barley (97 kg/ha) (1.8 bu/A), and Polish rapeseed (14.5 kg/ha) (13 lb/A) in rows 15 cm apart. Barley was omitted from a-2. Fertilizer, 16-20-0, at 90 kg/ha (80 lb/A) was broadcast on all plots just prior to rototilling and seeding. Germination was somewhat irregular only in rye plots in experiment a-1 but in experiment a-2, was uneven in all sprayed or unsprayed plots, except oats. An abundant growth of annual weeds also complicated experiment a-2. Seasonal precipitation (May to July) amounted to 24.4 cm. Spray drift from neighboring farm operations during the week of July 3 affected the flowers of buckwheat and rapeseed in both experiments which resulted in only crop forage weights being taken on August 2-4 and exclusion of seed yields. At this time barley and oats were at the heading stage. Data for crop and quack grass forage dry weights and heights were taken from random plot samplings of 0.85 m^2 quadrats. Rhizome samples were taken from 0.63 m^2 quadrats 15 cm deep.

b. Extended reduction of quack grass by winter rye seeded in fall 1972 after spray treatments and seeding of oats in spring 1972

This experiment was concerned with potential extension of reduction of quack grass in 1973 by fall (1972) seeded Frontier winter rye sown in plots sprayed with glyphosate and seeded to oats the preceding spring. A portion of the 1972 experiment concerning crop competition with and without glyphosate application (a-2 Saramaga farm) was continued, to measure the effects of both herbicide and continued crop competition during the season following the original treatments.

After harvesting the crops and control plots in August 1972, the oat plots that had been sprayed with 2.8 kg/ha glyphosate on May 20 and tilled on May 30 or tilled twice (May 20, 30) before seeding, were rototilled on August 24, 1972. Following rototilling, the plots were fertilized with 90 kg/ha, 16-20-0, granules applied to the surface and were seeded to Frontier winter rye at 1.25 kg/ha with a V belt disc seeder. Quack grass controls that had been tilled in the spring on dates noted above, were also tilled again and fertilized on August 24. Germination of rye in the fall (1972) and growth of rye in the spring (1973) was very good. Seasonal (1973) operations were hand weeding to remove a luxuriant growth of annual weeds and also periodic rototilling of 61 cm borders around each plot to prevent outside invasion of quack grass. Precipitation during the season (May through August) amounted to 29.5 cm. Plots were harvested during the week of August 16, 1973 using 0.85 m^2 quadrats for crop height, forage weights and seed yield as well as quack grass forage weights, shoot counts and height. Rhizomes were sampled from 0.63 m^2 quadrats 15 cm deep.

c. Oats and rye competition with quack grass with or without fall 1972 or spring 1973 glyphosate treatments

A field experiment testing oat and winter rye competition with quack grass with and without fall or spring applications of glyphosate was started in the fall of 1972. The experiment was established in a peaty clay loam soil west of Edmonton (Saramaga farm). The area had not been cropped for a year and was solidly infested with about 1050 quack grass shoots per m^2. Plots, 2.1 x 2.1 m for each treatment, were laid out in triplicate randomized blocks. A 61 cm

border strip was left around each plot for sprays with glyphosate and continual cultivation during the season to prevent quack grass re-invasion. The schedule of operations for the experiment is summarized in the following table (table 10). Fall or spring spray treatments were 2.8 kg/ha (2.5 lb/A) glyphosate in 281 l/ha (25 gal/A) water at 1.76 kg/sq cm (25 psi). The quack grass at D1 (fall) was 15 cm regrowth from mowing three weeks previously and the quack grass at D3 (spring) was 15 cm at the 2-3 leaf stage. About 0.25 cm of rain fell about nine hours after the fall applications but the spring applications were completed under ideal conditions. All cultivations, 13 cm deep, were done with a plot rototiller. A 4 row V belt disc seeder was used to seed Frontier winter rye at 94 kg/ha (1.5 bu/A) in the fall (D2) and Rodney oats at 95 kg/ha (2.5 bu/A) in the spring (D4). Plots scheduled for final treatment in the fall received a broadcast application of fertilizer (16-20-0) at 90 kg/ha (80 lb/A) during the final fall operation (D2), and those plots scheduled for spring treatments received a comparable fertilizer treatment during the final spring operation. During the growing season (1973) the plots were hand weeded several times to remove a luxuriant growth of annual weeds. Precipitation during the growing season (April to September) amounted to 37.8 cm. Plots involving treatments only in the fall of 1972 were harvested on August 23, and the remaining plots on September 10. Quadrats 0.85 m^2 were used for data on crop forage dry weights and seed yields as well as quack grass forage dry weights and shoot counts. Rhizome dry weights were from 0.63 m^2 quadrats 15 cm deep.

Table 10. Schedule of Operations (section 3-c)

	Fall (1972)		Spring (1973)	
	Date 1 (D1)	Date 2 (D2)	Date 3 (D3)	Date 4 (D4)
Treatment number	August 8	August 22	May 16	June 1
1	spray	cult & seed rye		
2	spray	cult & leave (control)		
3	cult	cult & seed rye		
4	cult	cult & leave (control)		
5	spray	leave until spring		cult & seed oats
6	spray	leave until spring		cult & leave (control)
7	cult	leave until spring		cult & seed oats
8	cult	leave until spring		cult & leave (control)
9	leave until spring		spray	cult & seed oats
10	leave until spring		spray	cult & leave (control)
11	leave until spring		cult	cult & seed oats
12	leave until spring		cult	cult & leave (control)

d. Crop competition with quack grass with or without glyphosate applications in 1973

Oats, buckwheat, rapeseed and rye competition with quack grass with and without spring glyphosate treatment was tested in an experiment on Malmo clay loam soil at Ellerslie farm in 1973. Triplicate plots 1.5 x 3 m were laid out in an area solidly infested with quack grass (900 shoots m^2) from rhizomes planted two years previously. Treatments involved spraying and cultivation before seeding the crops, cultivation before seeding, and unseeded controls. Sprayed plots received 2.8 kg/ha (2.5 lb/A) glyphosate in 281 l/ha (25 gal/A) water at 1.76 kg/sq cm (25 psi) May 14, when quack grass was 15-18 cm tall at 3-4 leaf stage. Conditions for spraying were ideal and no rain fell within twenty-four hours after spraying. Ten days later, when top-killing was complete, all plots were immediately fertilized with a surface application of 16-20-0 at 90 kg/ha (80 lb/A) prior to raking the plot area. Rodney oats (91 kg/ha (2.4 bu/A), Polish rapeseed (6.7 kg/ha (6 lb/A)), Tokyo buckwheat (64.5 kg/ha (1.2 bu/A)), and Frontier winter rye (88 kg/ha (1.4 lb/A)) were then seeded in rows 15 cm apart using a four row V belt disc seeder. Growth on some of the quack grass plots that were sprayed, cultivated and seeded to rye; cultivated and seeded to rye; and cultivated and left; was mowed five times during the growing season to simulate pasturing. The mowing dates were June 29, July 16, July 30, August 13 and finally on the harvest date August 27. Quack grass forage was separated from rye forage and dry weights were summed separately for the final forage weight values for quack grass and rye. Seasonal precipitation (May through August) amounted to 29 cm. The plots were

weeded during the growing season to remove annual weeds. The crops grew well but a frost in mid-August damaged tops of buckwheat, thus limiting its yield to forage. All yields were taken on August 27, except oats which matured on September 8. Crop forage dry weight and seed yields, and quack grass forage dry weights and shoot counts were taken from 0.85 m^2 quadrats. Quack grass rhizome dry weights were determined from quadrats 0.63 m^2, 15 cm deep.

B. Results, Discussion and Conclusions

1. Glyphosate dosage experiments with or without cultivation.

a. Effects of various dosages of glyphosate on quack grass with or without cultivation

A rain shower 8-10 hours after spraying operations may have affected the outcome of experiment a-1 and may have contributed to the variability in the experiment. Shoot counts, forage and rhizome weights were chosen as the major criteria for analysis of the results in this and the following field experiments, since data for height measurements of both quack grass and crops, where involved, showed less consistent differences between treatments. The results of this experiment indicated substantial reductions of quack grass forage weights but not rhizome weights in plots sprayed at 1.12 and 2.24 kg/ha rates of glyphosate in comparison with unsprayed controls. Glyphosate applied at 3.36 kg/ha reduced forage and rhizome regrowth to about 5-10% of that of the controls. Cultivation after sprays of 1.12 and 2.24 kg/ha rates of glyphosate was effective in reducing both forage and rhizome weights to about the same level as did 3.36 kg/ha glyphosate with or without cultivation. Many of the harvested rhizome samples from the glyphosate treated plots (1.12 and 2.24 kg/ha) had live sections interspersed between dead partially rotted sections. Many of the nodes in the live sections were developing a profusion of new shoots, somewhat similar to the symptoms of sublethal glyphosate injury noted in greenhouse experiments 1a and 1d. (Figures 1 and 2).

In experiment a-2 (table 11) increasing rates of glyphosate resulted in increasing reductions of quack grass regrowth which in all

Table 11. Effects of various dosages of glyphosate on quack grass with or without cultivation. (Means of 3 replications).

Treatment glyphosate + or - cult. kg/ha (lb/A)	Shoot count per m^2 area	Forage wt (dry) g/m^2 area	Rhizome wt (dry) g/m^2*** area
Control - cult	1764a**	314a*	685a*
Control + cult	758 b	44 b	145 b
1.12 (1) - cult	134 c	10 bc	20 bc
1.12 (1) + cult	93 c	6 bc	19 bc
2.24 (2) - cult	113 c	8 bc	14 c
2.24 (2) + cult	65 c	3 c	5 c
3.36 (3) - cult	45 c	3 c	9 c
3.36 (3) + cult	34 c	2 c	5 c

*Means followed by the same letter are not significantly different using Duncan's Multiple Range Test (Duncan 1955)
*Significant at 5%
**Significant at 1%
***Results from 0.63 m^2 areas 15 cm deep extrapolated to m^2 areas 15 cm deep

cases were significantly better than the control and which left as little as 6% of the amount of regrowth which occurred in the cultivated control. Also in comparing each treatment without cultivation with the corresponding treatment with cultivation, the trends of the data indicate that cultivation did increase control of quack grass. The analyses, however, show significant effects of cultivation only between the uncultivated and cultivated control. The treatments involving glyphosate were not significantly different from each other but reductions of quack grass forage weight from 2.24 kg/ha treatment without cultivation and rhizome weight after 1.12 kg/ha spray plus cultivation were not significantly different from the cultivated control. The results therefore indicate that glyphosate applied at higher dosages between 2.24 and 3.36 kg/ha were most effective for quack grass control. This finding supports the reasonableness of choosing the dosage rate of 2.80 kg/ha glyphosate used for quack grass control in crop experiments which will be discussed in the latter part of the field experiments section.

At harvest, the volume of viable rhizomes per plot was much lower than comparable treatments in experiment a-1. Also there were only a few rhizomes in plots treated with 1.12 and 2.24 kg/ha which had living sections along what appeared to be a dead rhizome , and there was no profuse shoot development as in experiment a-1. These results suggest that the effectiveness of glyphosate sprays in experiment a-1 may have been reduced by the rain shower which occurred after spraying.

b. <u>Effects of cultivation on quack grass before and/or after the application of glyphosate</u>

The glyphosate treatments and treatments involving only cultivation,significantly reduced quack grass shoot counts, and forage and rhizome dry weights compared to the untilled control (table 12). Also during the first year of this experiment the till, till, till treatment (tr 5) reduced shoot counts, and forage and rhizome regrowth comparable to glyphosate treatments. The repeated tillage (tr 5) induced similar reductions in forage and rhizomes but greater decreases in shoot counts compared with the leave, till, till treatment (tr 6). All glyphosate treatments, except treatment 1 (till, spray, leave) on the other hand, produced significantly better control than the treatment leave, till, till (tr 6). The results also indicated that there was no apparent advantage from cultivation after spraying quack grass at the heading stage (tr 3 vs. tr 4). However, cultivation of quack grass sprayed in the vegetative stage following earlier cultivation was very beneficial (tr 2 vs. tr 1).

Continued records during the second year for tillage only,treatments (tr 5 and 6) and the till, spray, leave (tr 1) table 13, indicate that their only significant difference from the uncultivated control (tr 7) occurred in reduction of rhizome regrowth. Cultivation, although reducing the weight of rhizomes per plot, may have stimulated dormant buds on the remaining rhizomes to produce the high shoot counts and forage weights existing in the plots. As is noted in the 1972 results, the treatments involving glyphosate applications (tr 2, 3, 4) were most effective in reducing quack grass regrowth of both forage and rhizomes.

Table 12. Effects of cultivation on quack grass before and/or after glyphosate application in 1972. (Means of 3 replications).

Treatment number (Table 9)	Treatment			Shoot count per m^2 area	Forage dry wt g/m^2 area	Rhizome dry wt g/m^{2**} area
	D1 May 8	D2 June 15	D3 June 27			
7	Leave	Leave	Leave	1417a*	485a*	823a*
6	Leave	Till	Till	835 b	139 b	137 b
5	Till	Till	Till	290 c	59 bc	70 bc
1	Till	Spray	Leave	158 c	40 bc	57 bc
4	Leave	Spray	Till	50 c	4 c	7 c
2	Till	Spray	Till	28 c	4 c	2 c
3	Leave	Spray	Leave	33 c	2 c	1 c

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan 1955)

**Results from 0.63 m^2 areas 15 cm deep extrapolated to m^2 areas 15 cm deep

Table 13. Effects on quack grass in 1973, one year after treatment involving cultivation of quack grass before and/or after application of glyphosate. (Means of 3 replications).

Treatment number (Table 9)	Treatment D1 May 8	Treatment D2 June 15	Treatment D3 June 27	Shoot count per m^2 area	Forage dry wt g/m^2 area	Rhizome dry wt g/m^2*** area
7	Leave	Leave	Leave	910a*	294a**	619a*
6	Leave	Till	Till	864a	306a	198 b
5	Till	Till	Till	751a	275a	147 bc
1	Till	Spray	Leave	522ab	210ab	147 bc
4	Leave	Spray	Till	305 bc	68 bc	67 cd
2	Till	Spray	Till	178 bc	40 c	34 d
3	Leave	Spray	Leave	147 c	45 c	12 d

Means followed by the same letter are not significantly different using Duncan's Multiple Range Test (Duncan 1955)

*Significant at 5%

**Significant at 1%

***Results from 0.63 m^2 areas 15 cm deep extrapolated to m^2 areas 15 cm deep

Moreover, the carry-over effects in 1973 indicated that cultivation after spraying at heading time (tr (4) leave, spray, till) in fact reduced the effectiveness of glyphosate compared to no cultivation before or after spraying at heading time (treatment (3) leave, spray, leave). The latter procedure was as effective as the treatment (2) till, spray, till. The end result of tr 3 (leave, spray, leave) was an approximately 80% reduction in shoot counts, 84% reduction in shoot counts, 84% reduction in forage weight and over 90% reduction in rhizomes compared with tr 5 involving three tillage operations.

c. Influence on quack grass of various periods of delay before removing top growth after glyphosate application

The results for shoot counts (figure 5) and forage weights (figure 6) indicate that there were no appreciable decreases in quack grass regrowth following delays in mowings longer than two days after spraying 2.8 kg/ha or 1.68 kg/ha glyphosate. Figure 7 illustrates the limited quack grass regrowth fifty days after mowing a plot one day after 2.80 kg/ha spray application. Figure 8 shows the corresponding mowed unsprayed control. Translocation of lethal quantities of glyphosate from sprayed top growth to rhizomes apparently was more rapid at the higher rate of glyphosate but after two days the results of the two rates were comparable and highly effective. If similar results can be achieved from spraying of vegetative quack grass early in the spring, followed by only a short delay before cultivation and seeding of a crop, this would, of course, be a distinct advantage in maximizing the use of the growing season.

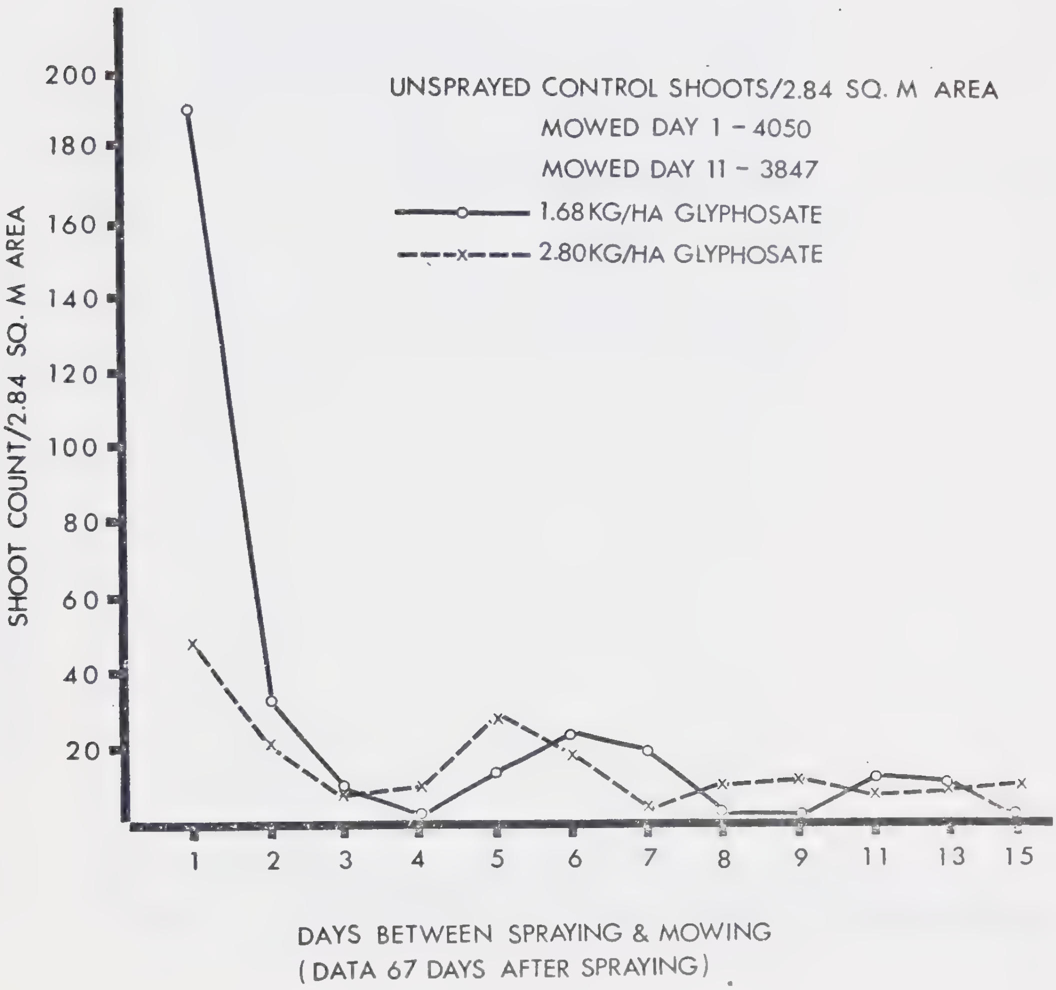

Figure 5. Effects on shoot regrowth of quack grass after foliage sprays with glyphosate and mowing at different times after spraying. From day 2 onward there were no significant differences at the 1% level (Duncan 1955).

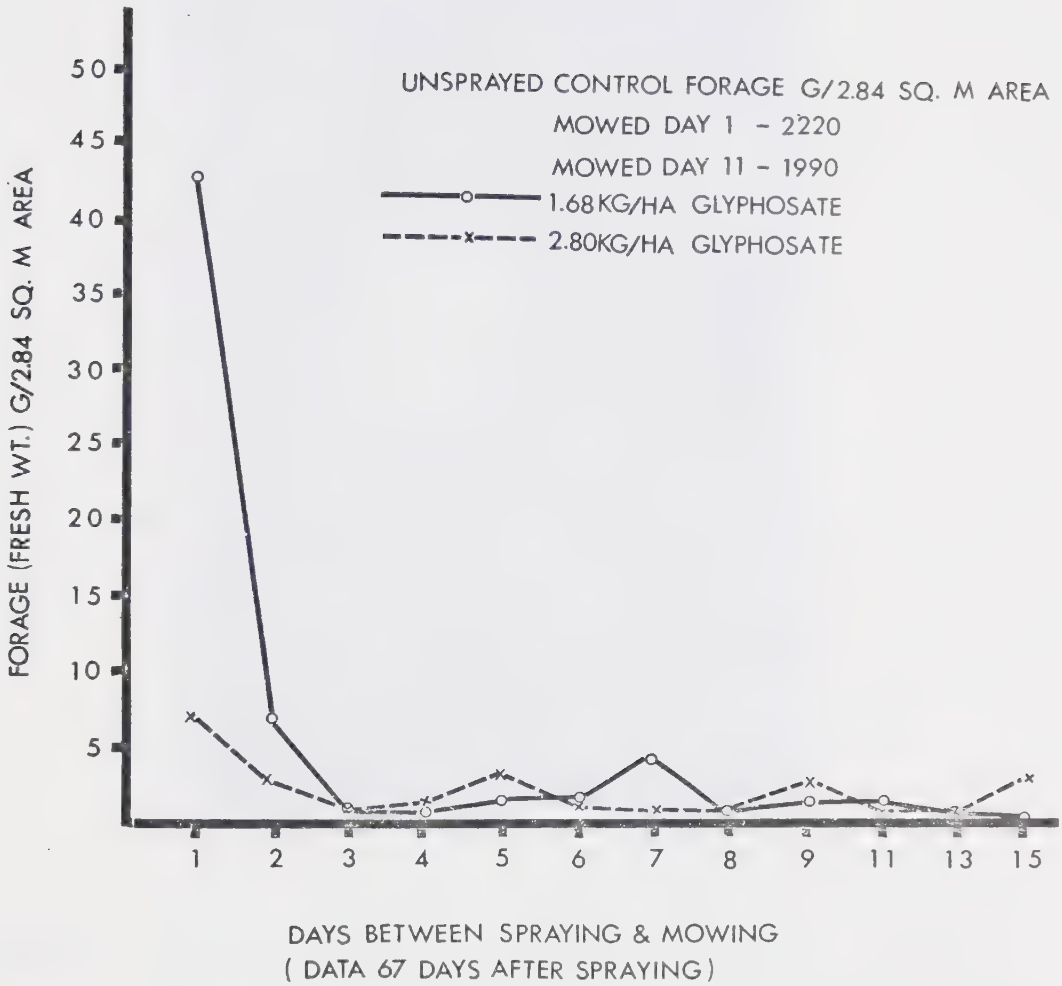

Figure 6. Effects on fresh weight of forage regrowth of quack grass after foliage sprays with glyphosate and mowing at different times after spraying. (Means of 2 replications). Only the weight at day 1 for 1.68 kg/ha is significantly different from the remaining treatments at the 1% level (Duncan 1955).

Figure 7. Virtual absence of regrowth 50 days after spraying 2.80 kg/ha glyphosate on quack grass at heading stage, mowed one day after spraying.

Figure 8. Extensive regrowth in control plot 49 days after mowing unsprayed quack grass at the heading stage. (For comparison with the glyphosate sprayed area in fig 7, mowed one day after spraying).

2. Quack grass seedling competition with oats, rapeseed, buckwheat and winter rye..

Development from its seeds began very slowly but by harvest, ninety days later, quack grass had produced a vigorous growth of forage (76 cm high) and of rhizomes, indicating its potential as a strong competitor.

Of the crops grown in competition with the quack grass seedlings, oats, buckwheat and rye were most effective in reducing the development of quack grass forage,and oats and buckwheat for reducing rhizomes (table 14). Rhizome development has been related directly to light intensity for the plants (Palmer 1958; Williams 1970a). Observations and results of the present experiments tend to support that view since oats and buckwheat produced a denser canopy of growth than rapeseed or winter rye.

The percentage forage yield reduction of rapeseed was affected less than the other crops but oats produced both a significantly greater quantity of forage and seed (table 15). On balance then, oats was the most effective from the standpoint of combined crop productivity and competition against young quack grass.

3. Crop competition with quack grass with and without glyphosate application

a. Crop competition with quack grass with and without glyphosate application in 1972

The results of experiment a-2 (table 16) indicate that all of the treatments involving glyphosate sprays with or without cropping and those treatments involving cultivation and cropping, significantly

Table 14. Reduction of seedling quack grass by competition with oats, rapeseed, buckwheat and winter rye. (Means of 4 replications).

Crop	Quack grass forage dry g/m^2 area	Reduction of quack grass forage as % of uncropped quack grass	Quack grass rhizome dry wt g/m^2** area	Reduction of quack grass rhizomes as % of uncropped quack grass
Oats	112a**	78	8a*	95
Rapeseed	283 b	44	66 b	59
Buckwheat	129a	75	11a	93
Winter rye	192ab	62	76 b	53
Quack grass (uncropped control)	507 b		162 c	

Means followed by the same letter are not significantly different using Duncan's Multiple Range Test (Duncan 1955)

*Means significant at 5%

**Means significant at 1%

**Results from 0.63 m^2 areas 15 cm deep extrapolated to m^2 areas 15 cm deep

Table 15. Reduction of oats, rapeseed, buckwheat and winter rye from competition with quack grass seedlings. (Means of 4 replications).

Crop + or - quack grass	Crop forage dry wt g/m^2 area	Reduction of crop as % of quack-free crop	Crop seed wt g/m^2 area	Reduction of crop seed yield as % of quack-free crop
Oats	1296a*		367a*	
Oats & quack grass	816 b	37	221 b	40
Rapeseed	415 cd		103 c	
Rape & quack grass	349 d	16	50 c	51
Buckwheat	562 c		Frost	
Buckwheat & quack grass	348 d	38	Frost	
Winter rye	552 c		—	
Rye & quack grass	311 d	44	—	

*Means followed by the same letter are not significantly different at the 1% level using Duncan's Multiple Range Test (Duncan 1955)

Table 16. Effects of glyphosate, cultivation, and cropping on control of quack grass and on crop yields. (Means of 3 replications).

Treatment number (Table 9)	Treatment (spray = 2.80 kg/ha glyphosate)	Shoot count per m^2 area	Forage dry wt g/m^2 area	Rhizome dry wt g/m^2** area	Crop forage dry wt g/m^2 area
1	spray, cult & seed oats	60a*	4a*	5a*	357a
2	spray, cult & seed rye	76a	5a	10a	82 b
3	spray, cult & leave	147a	7a	26a	
4	spray, leave	194a	8a	46ab	
5	cult 2x & seed oats	558 b	63 b	80ab	278a
6	cult 2x & seed rye	772 b	80 b	112 b	53 b
7	cult 2x, leave	1094 c	136 c	228 c	

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan 1955)

**Results from 0.63 m^2 areas 15 cm deep extrapolated to m^2 areas 15 cm deep

reduced quack grass regrowth compared with the treatment involving cultivation only (tr 7). Treatments in which glyphosate was used, significantly reduced shoot counts and forage dry weights compared with the treatments which did not involve glyphosate. On the other hand, rhizome reductions in plots cultivated twice and seeded to oats (tr 5) were comparable to those of spray treatments. Moreover, the treatment cultivated twice and seeded to rye reduced rhizome regrowth comparable to that of the spray treatment that was left without cultivation (tr 4). Although the two glyphosate treatments that did not involve cropping (tr 3, 4) produced results that were not significantly different from spraying followed by cropping (tr 1, 2), there was an evident tendency for less quack grass regrowth on latter plots. Quack grass regrowth in plots cultivated and sown to crops (tr 5 and 6), although, in general, more abundant than in sprayed plots, was nevertheless, significantly less than after a similar treatment without a crop (tr 7). These results indicate the potential of oats and rye as important factors in reducing quack grass regrowth in sprayed or cultivated areas. On cultivated unsprayed areas they reduced quack grass forage weight by about 47% and rhizome weight by about 60% compared with the weights from corresponding areas not cropped. Although oats and rye, in this experiment (a-2), were apparently equally effective in reducing quack grass regrowth, oats produced more than four times more forage in both sprayed and unsprayed plots (tr 1 and 5) than spring seeded winter rye grown in comparable treatments (tr 2 and 6). The results of experiment a-1 were similar to the results already discussed for experiment a-2 (a-1 results were not put in a

table since the experiment consisted of unreplicated plots.) In addition, however, since the rapeseed and buckwheat in a-2 were discarded because of the great variability in establishment and in growth, the observations and results for these crops grown in experiment a-1, indicated that their competitive ability exceeded that of oats, rye and barley. Barley was included only in experiment a-1, but, judging by the limited data available, it was comparable to oats and rye in competitive ability. Another experiment in section d provides more information on the relative competitive abilities of oats, rapeseed, buckwheat and rye.

b. Extended reduction of quack grass by winter rye seeded in fall, 1972, after spray treatments and seeding of oats in spring, 1972

Glyphosate application and cropping with oats in the spring of 1972 followed by post harvest seeding of rye in the fall of that year (tr 1, table 17) resulted in quack grass in 1973 being only 7% of that growing in the cultivated control (tr 3). Also, regrowth of quack grass in 1973 after competition with winter rye, was not much greater than regrowth present at harvest time in the same plots in 1972 after spraying and seeding to oats (tr 1, table 16). The results of the treatment involving cultivation, seeding and harvesting oats before seeding winter rye in 1972 (tr 2, table 17) were, by 1973, not significantly different from treatment 1 which included glyphosate spraying before seeding oats. The crop sequence without spraying had quack grass shoot counts of 31% and rhizome weights of 39% of the corresponding figures for the cultivated control (tr 3). Forage weights of quack grass in this treatment, on the other hand, were not

Table 17. Extended reduction of quack grass by winter rye seeded in fall, 1972, after spray treatments and seeding of oats in spring, 1972. (Means of 3 replications).

Treatment number	Treatment (spray = 2.80 kg/ha glyphosate) 1972 Spring	1972 Fall	Shoot count per m^2 area	1973 Forage dry wt g/m^2 area	Rhizome dry wt g/m^2*** area
1	spray, cult & seed oats	cult & seed rye	95a**	14a**	23a*
2	cult 2x & seed oats	cult & seed rye	374a	80ab	125a
3	cult 2x leave	cult & leave	1215 b	285 b	323 b

Means followed by the same letter are not significantly different using Duncan's Multiple Range Test (Duncan 1955)

*Significant at 5%

**Significant at 1%

***Results from 0.63 m^2 area 15 cm deep extrapolated to m^2 areas 15 cm deep

significantly different from the control. In 1973 winter rye, in treatment 2, reduced the shoot counts but forage and rhizomes had increased compared to quack grass regrowth in the fall of 1972, in the same plots, when the oats were harvested (tr 5, table 16).

Observations, in the fall of 1973, of plots sprayed with glyphosate in the spring of 1972 but not seeded (tr 3, table 16), indicated that quack grass had regrown profusely and was comparable to that of the plots which were cultivated twice in the spring of 1972 (tr 7, table 16) and cultivated again in the fall (tr 3, table 17) in this winter rye experiment. Moreover, the regrowth of quack grass in the sprayed plots, in this experiment, was much greater than it was in the year following glyphosate applications in experiment 1b (table 13, tr 2, 3, 4). Since both experiments, 1b and 3a, were conducted on patches of quack grass of similar density and in the same soil type and in close proximity to each other, there seems to be no definite explanation for the extent of the differences in regrowth. Differences in timing of the operations may, however, have had some effect in this connection.

Rye forage production in treatment 1 (spray, cultivate, seed oats in spring, 1972, cultivate and seed rye in the fall, table 18) was significantly different than it was in treatment 2 (cultivate twice, seed oats in 1972, cultivate, seed rye in the fall, 1972), although seed production was not significantly different between treatments. Forage production of rye in both treatments in 1973, on the other hand, was greater than oat production in these same plots (tr 1, 5, table 16) in 1972.

In summary, oats following glyphosate spray during the initial

Table 18. Effects of quack grass regrowth after spray treatments and seeding of oats in spring, 1972, on winter rye sown in the fall, 1972. (Means of 3 replications).

Treatment number (Table 17)	Treatment (spray = 2.80 kg/ha glyphosate) 1972 Spring	1972 Fall	1973 Crop forage dry wt g/m^2 area	seed yield g/m^2 area
1	spray, cult & seed oats	cult & seed rye	710a*	302a
2	cult 2x & seed oats	cult & seed rye	526 b	246a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Nultiple Range Test (Duncan 1955).

crop year induced greater reductions in quack grass than occurred when oats were seeded on unsprayed, cultivated land. Although this difference did not persist with rye during 1973, there continued to be a very significant difference with regard to retardation of reinvasion of quack grass in the cropped areas in contrast with the uncropped control. Also forage weights of rye for treatments involving glyphosate and cropping, and cultivation and cropping, in the spring (tr 1, 2, table 18) were greater than the oats grown in these treatments in 1972 (tr 1 and 5, table 16).

c. Oats and rye competition with quack grass with or without fall 1972 or spring 1973 glyphosate treatments

Treatments involving glyphosate sprays resulted in comparable levels of quack grass control whether cultivation or cultivation and seeding of crops followed spraying (table 19). However, these treatments were significantly more effective in reducing quack grass than those treatments involving cultivation with or without subsequent seeding of crops, with two exceptions: the treatment, cultivate fall, cultivate spring, seed oats (tr 7) had forage and rhizome weights but not shoot count reductions comparable to the sprayed plots; the treatment, cultivate two times in spring and seed oats (tr 11) had rhizome reductions but not shoot count or forage weight reductions comparable to the spray fall, cultivate fall, leave treatment (tr 2). In comparing treatments involving only cultivation, the treatment cultivate fall, cultivate spring, seed oats (tr 7), was the most effective in reducing quack grass regrowth. In comparison with the unseeded control, the crop induced an additional 67% reduction of quack grass. It was

Table 19. The effects on quack grass of various combinations of tillage with or without glyphosate treatments and cropping with oats or rye. (Means of 3 replications)

Treatment number (Table 10)	Treatment (spray = 2.80 kg/ha glyphosate)	Shoot count per m^2 area	Forage dry wt g/m^2 area	Rhizome dry wt g/m^2** area
5	Spray fall, cult & seed oats spring	28a*	4a*	2a*
9	Spray spring, cult & seed oats spring	45a*	7a	8a
1	Spray fall, cult & seed rye	110a	16a	12a
10	Spray fall, cult spring & leave	220a	28a	13a
6	Spray spring, cult & leave	202a	20a	28a
2	Spray fall, cult fall & leave	200a	34a	42ab
7	Cult fall, cult spring & seed oats	403 b	64a	44ab
11	Cult 2x spring & seed oats	767 bc	166 b	89 bc
3	Cult 2x fall & seed rye	650 bc	133 b	139 cd
8	Cult fall, cult spring & leave	1258 cd	170 b	168 de
4	Cult 2x fall & leave	983 cd	262 c	294 f
12	Cult 2x spring & leave	1626 d	287 c	217 e

*Means followed by the same letter are not significantly different at the 1% level using Duncan's Multiple Range Test (Duncan 1955)

**Results from 0.63 m^2 areas 15 cm deep were extrapolated to m^2 areas 15 cm deep

significantly better than the corresponding treatment which was not sown to a crop (tr 8). Also the treatments, cultivate twice in the spring, seed oats (tr 11), and cultivate twice in the fall, seed rye (tr 3), although showing no differences between the treatments, did give evidence of the competitive effects of these crops. They provided significantly better quack grass control than the respective control treatments which were not seeded to crops (tr 12 and 4).

Crop forage weights and seed yields of oats and rye grown in plots treated with glyphosate were not significantly different from each other. However, they were significantly better than the crop yields from oats and rye sown into plots receiving only cultivation prior to seeding (table 20). This can be attributed to the fact, indicated earlier, that quack grass reductions were greatest in plots receiving glyphosate treatments. Apparently oats and rye, as managed in the experiment, were equally effective competitors against quack grass and their yields were about equally improved by the use of glyphosate spray, *viz.* about 50%. The associated reduction in quack grass forage and rhizomes was approximately 92% of the amount present in the crops not receiving spray in addition to cultivation.

d. Crop competition with quack grass with or without glyphosate application in 1973

Treatments 1-6 (table 21), all involving glyphosate, averaged about 97% control of quack grass compared to the treatment cultivate, leave (tr 14). These treatments produced significantly better control, with one exception (tr 7; cultivate, seed rye, mow five times), than treatments which were either without spraying or without cropping.

Table 20. Forage and seed yields of oats and rye in cultivated quack grass plots with or without glyphosate treatments. (Means of replications).

Treatment number (Table 10)	Treatment (Spray = 2.8 kg/ha glyphosate)	Crop forage dry wt g/m^2	Seed yield g/m^2
9	Spray spring, cult & seed oats spring	678a*	292a*
1	Spray fall, cult & seed rye	666a	272a
5	Spray fall, cult & seed oats spring	641a	264a
7	Cult fall, cult spring & seed oats	368 b	166 b
3	Cult 2x fall & seed rye	345 b	149 b
11	Cult 2x spring, seed oats	288 b	133 b

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan 1955)

Table 21. Effects on quack grass of crop competition with or without glyphosate applications. (Means of 3 replications).

Treatment number	Treatment (spray = 2.80 kg/ha glyphosate)	Shoot count per m^2 area	Forage wt (dry) g/m^2 area	Rhizome wt (dry) g/m^2*** area
1	Spray, cult & seed buckwheat	7a**	2a**	2a*
2	Spray, cult & seed oats	9a	3a	7a
3	Spray, cult & seed rapeseed	12a	5a	4a
4	Spray, cult & seed rye	20a	14a	18a
5	Spray, cult & seed rye, mow 5x	25a	5a	4a
6	Spray & leave	87a	33a	33a
7	Cult & seed rye, mow 5x	162ab	84ab	62ab
8	Spray, cult & leave	175ab	79ab	74ab
9	Cult & mow quack grass regrowth 5x	404 b	179 b	137 b
10	Cult & seed oats	460 c	285 c	131 b
11	Cult & seed rapeseed	614 c	500 d	309 cd
12	Cult & seed rye	636 c	467 de	369 d
13	Cult & seed buckwheat	987 d	589 ef	239 c
14	Cult & leave	985 d	694 f	343 d

Means followed by the same letter are not significantly different using Duncan's Multiple Range Test (Duncan 1955)

*Significant at 5%

**Significant at 1%

***Results from 0.63 m^2 areas 15 cm deep were extrapolated to m^2 areas 15 cm deep

Also, treatment 6 (spray, leave), has data which, although not significantly different from treatments 1-5, does indicate poorer quack grass control than was achieved by the spray plus cropping procedure. Treatment 7 (rye seeded after cultivation and mowed five times to simulate grazing), had about 85% less quack grass than the cultivate, leave treatment (tr 14). As noted above, results of treatment 7 were not significantly inferior to the spray treatments, and with the exception of a comparable amount of rhizomes after treatment 10 (cultivate, seed oats), were distinctly better for reducing quack grass than were the procedures involving cultivation followed by crops harvested once at the end of the season (tr 10-13, table 22). Even repeated mowings of quack grass without a competing rye crop (tr 9, table 21) had some, though smaller, advantage over such crops.

Oats (tr 2) and rapeseed (tr 3) grown in plots where quack grass was sprayed with glyphosate prior to seeding, produced comparable quantities of crop forage but oats had a significantly higher seed yield (table 23). Buckwheat (tr 1) sown into plots sprayed with glyphosate prior to seeding had forage yields comparable to those for rapeseed. Figure 9 shows rapeseed growing in a plot which was only cultivated prior to seeding and figure 10 indicates rapeseed grown in a plot sprayed with glyphosate prior to seeding. Crop forage weights from crops grown in sprayed plots in this experiment were comparable to crop forage yields taken from adjacent crops grown in weed-free plots.

Oats grown in cultivated plots (tr 10) not only produced forage yields comparable to buckwheat (tr 1) and rye (tr 4 and 5) grown on

Table 22. Competition between crops and quack grass regrowth after cultivation. (Means of 3 replications). (% reductions derived from Table 21 and Table 23).

	Treatment cultivation & seeding	Quack grass forage dry wt g/m^2 area	% reduction of quack grass forage vs. cult control	Quack grass rhizome dry wt g/m^2* area	% reduction of quack grass rhizomes vs. cult control	crop forage dry wt g/m^2 area	% reduction of crops vs. crops grown in sprayed areas**
10	oats	285	58	131	62	544	51
11	rape	500	28	309	10	194	78
12	buckwheat	589	15	239	30	160	74
13	rye (winter)	467	33	369	0	92	80
14	control (cultivated)	694		343			

*Results from 0.63 m^2 areas 15 cm deep were extrapolated to m^2 areas 15 cm deep

**Results for crops grown in sprayed areas Table 23 (oats tr 2, rapeseed tr 3, buckwheat tr 1, rye tr 4)

Table 23. Effects on crops of quack grass regrowth from treatments involving cultivations with or without glyphosate. (Means of 3 replications).

Treatment number (Table 21)	Treatment (spray = 2.80 kg/ha glyphosate)	Crop forage dry wt g/m^2 area	Seed yield g/m^2 area
2	Spray, cult & seed oats	1129a**	489a*
3	Spray, cult & seed rapeseed	904ab	249 b
1	Spray, cult & seed buckwheat	632 bc	Frost
10	Cult & seed oats	544 cd	183 c
4	Spray, cult & seed rye	460 cde	—
5	Spray, cult & seed rye, mow 4x	280 def	—
7	Cult, seed rye, mow 4x	196 ef	—
11	Cult, seed rape	194 ef	38 d
13	Cult, seed buckwheat	160 f	Frost
12	Cult, seed rye	92 f	—

Means followed by the same letter are not significantly different using Duncan's Multiple Range Test (Duncan 1955)

*Significant at 5%

**Significant at 1%

Figure 9. Extensive regrowth of quack grass after only cultivation prior to seeding rapeseed. Contrast with glyphosate sprayed area, fig 10.

Figure 10. Near absence of quack grass regrowth after glyphosate spray at 2.80 kg/ha prior to cultivation and seeding rapeseed.

sprayed land (table 23) but was affected less by quack grass competition (table 22) than all crops grown in plots that were not sprayed but only cultivated prior to seeding and which were harvested once in the fall. Oats grown in cultivated plots also produced significantly more seed than rapeseed grown on cultivated land.

Oats, whether grown in plots sprayed or cultivated prior to seeding, reduced quack grass as much or more than did other crops sown after similar preseeding treatments. This and the fact that oat yields from sprayed or cultivated plots were, again, as good or better than other crops grown in plots with similar preseeding treatments suggests that oats was the best crop competitor.

SUMMARY

In greenhouse experiments, herbicidal effects of glyphosate on quack grass rhizomes after spraying single shoots growing from severed sections of the rhizome were similar to the effects of spraying corresponding shoots from the same total length of intact rhizome. This suggests that, under field conditions, tillage to break rhizomes prior to spraying shoot regrowth may be of no advantage for the action of glyphosate.

Results from spraying glyphosate on either the end or central shoots of rhizomes, in greenhouse flats, showed that herbicidal action occurred both toward and away from the parent plant end of the rhizomes. Occasionally shoots along a rhizome remained living, apparently partially by-passed by the herbicide, while shoots more remote from the site of treatment died. Some similar effects occurred in the field, indicated by small, live sections of excavated rhizome between dead portions of the same rhizome.

There were some toxic effects on rapeseed and buckwheat sown in soil sprayed with high dosages of glyphosate (4.48, 6.72, and 8.96 kg/ha for rapeseed and 8.96 kg/ha for buckwheat) and grown in the growth chamber but there was no detectable evidence of any effects on any of the crops in areas treated with 2.8 kg/ha in the field.

Field experiments on cropland involving cultivation fourteen days after spring spraying of dense quack grass stands when its top growth had died, indicated that a dosage between 2.24 and 3.36 kg/ha a.e. of glyphosate was optimum. There was generally less improvement of results by increasing the rate from 2.24 to 3.36 kg/ha than from 1.12

to 2.24 kg/ha. In all cases, glyphosate spray at 2.48 kg/ha followed by cultivation was more effective for quack grass control than cultivation followed by cultivation at corresponding times.

Field applications of glyphosate to quack grass in early heading stage after no spring cultivation, and not followed by cultivation, were as effective during the first summer (1972) as when cultivation followed such spraying. Moreover, quack grass sprayed at the same time, in a vegetative 2-4 leaf stage of regrowth after spring cultivation, then cultivated again sixteen days after spraying, was controlled as effectively as it was by the foregoing procedures involving spraying at heading time. However, during 1973 there was more regrowth in the plots which had been cultivated after spraying at heading time in 1972 than there was in either the plots undisturbed after such spraying, or in the plots cultivated again after spraying at the vegetative stage in 1972.

Field spraying of glyphosate on quack grass at heading stage in July, followed by removal of all top growth by mowing at different times, delayed up to fifteen days after spraying, indicated that no more than two days delay were necessary to permit maximum herbicidal effect on limitation of regrowth from the rhizomes during a period of more than two months after spraying.

There was vigorous competition of seeded quack grass, in its seedling season, with oats, buckwheat, rapeseed and spring sown winter rye in the field. The crops in order of decreasing effect against the quack grass were oats, buckwheat, winter rye and rapeseed. Oats gave the highest yield of forage and seed. Treatments involving

glyphosate sprays on dense, established quack grass followed by cropping with oats, rapeseed, buckwheat and winter rye reduced quack grass about 97% compared with cultivated uncropped controls. Spring sown crops planted in plots cultivated but not sprayed prior to seeding, reduced quack grass regrowth (forage and rhizomes) by an average of from 15 to 60% compared to the cultivated uncropped control. However, crops grown in these plots suffered yield losses of between 50 and 80% compared to crop production in sprayed plots. Oats had the greatest effects on quack grass reductions and also produced the greatest crop yields. Rapeseed and buckwheat had somewhat less effect on quack grass and poorer yields than oats. Spring seeded winter rye suffered the greatest losses from quack grass competition and also had the least effect on the quack grass. However, another treatment involving cultivated unsprayed quack grass which was sown to winter rye in spring and mowed five times during the growing season to simulate pasturing, resulted in quack grass control comparable to some of the glyphosate and cropping treatments.

Winter rye seeded in the fall immediately after harvesting oats grown on quack grass infested land sprayed with glyphosate in the previous spring, appreciably reduced recovery of quack grass during the following year.

Fall seeded rye and spring seeded oats on quack grass land not in crop the previous summer were equally productive and nearly equally effective in limiting growth of quack grass. Oats may have been somewhat superior. Both crops produced about 50% more yield on sprayed plots than on unsprayed controls, and reductions in quack grass forage

and rhizomes were approximately 92% of the amount present in the crops not receiving spray in addition to cultivation. Also cultivations twice in the fall or twice in the spring were less effective in reducing quack grass than one cultivation in the fall and another cultivation in the spring.

Fall treatments involving glyphosate were more effective than cultivation alone, but no more beneficial for quack grass control and crop production than corresponding spring spray treatments prior to seeding the crop.

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